Geant 4

Geant4

Makoto Asai (SLAC PPA/SCA)

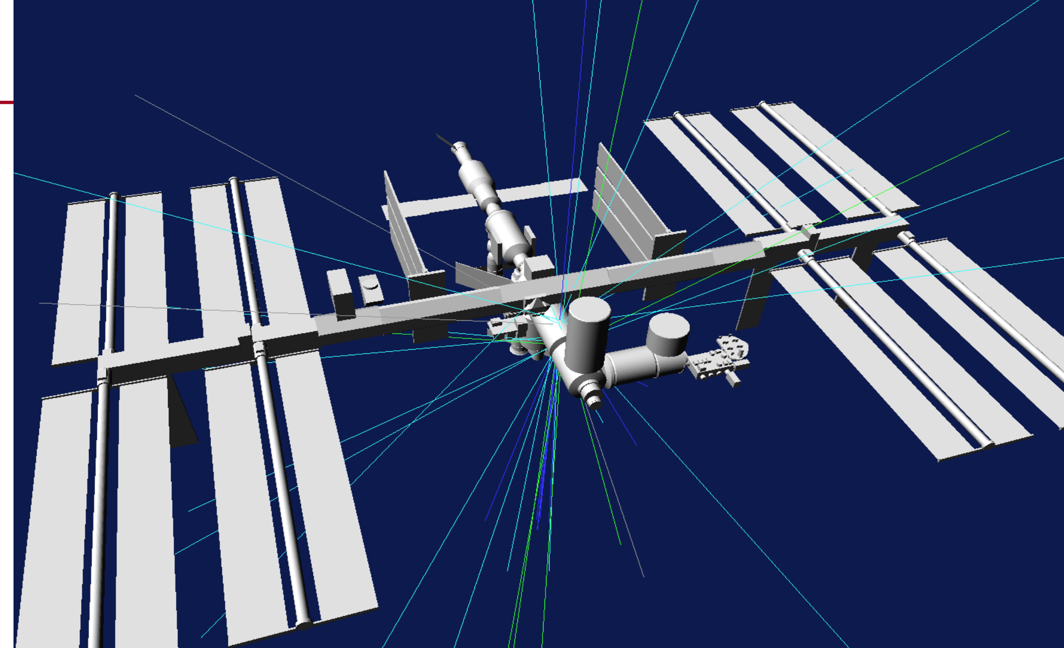
Workshop on HPC and Super-computing for Future Science Applications

June 5th, 2013

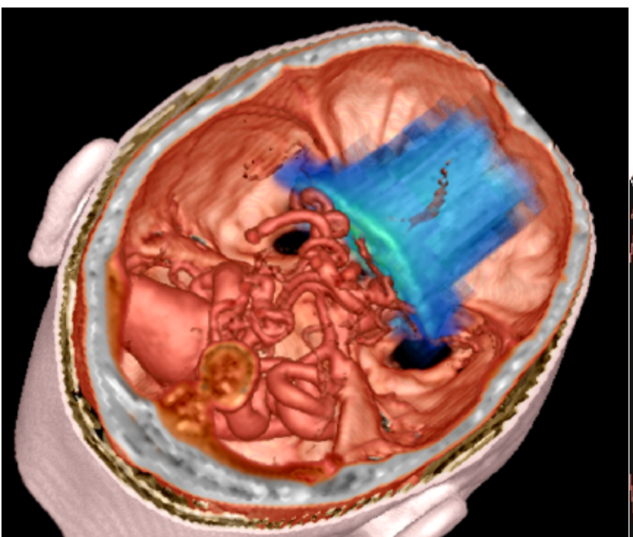
SLAC NATIONAL ACCELERATOR LABORATORY

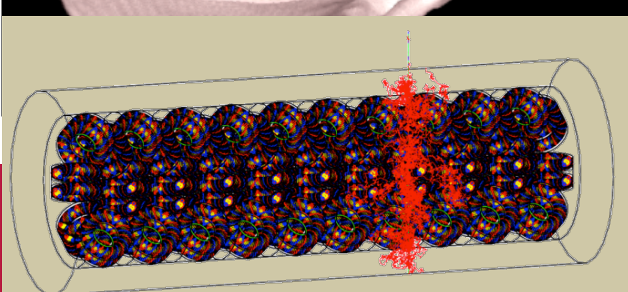
U.S. DEPARTMENT OF ENERGY
Office of Science

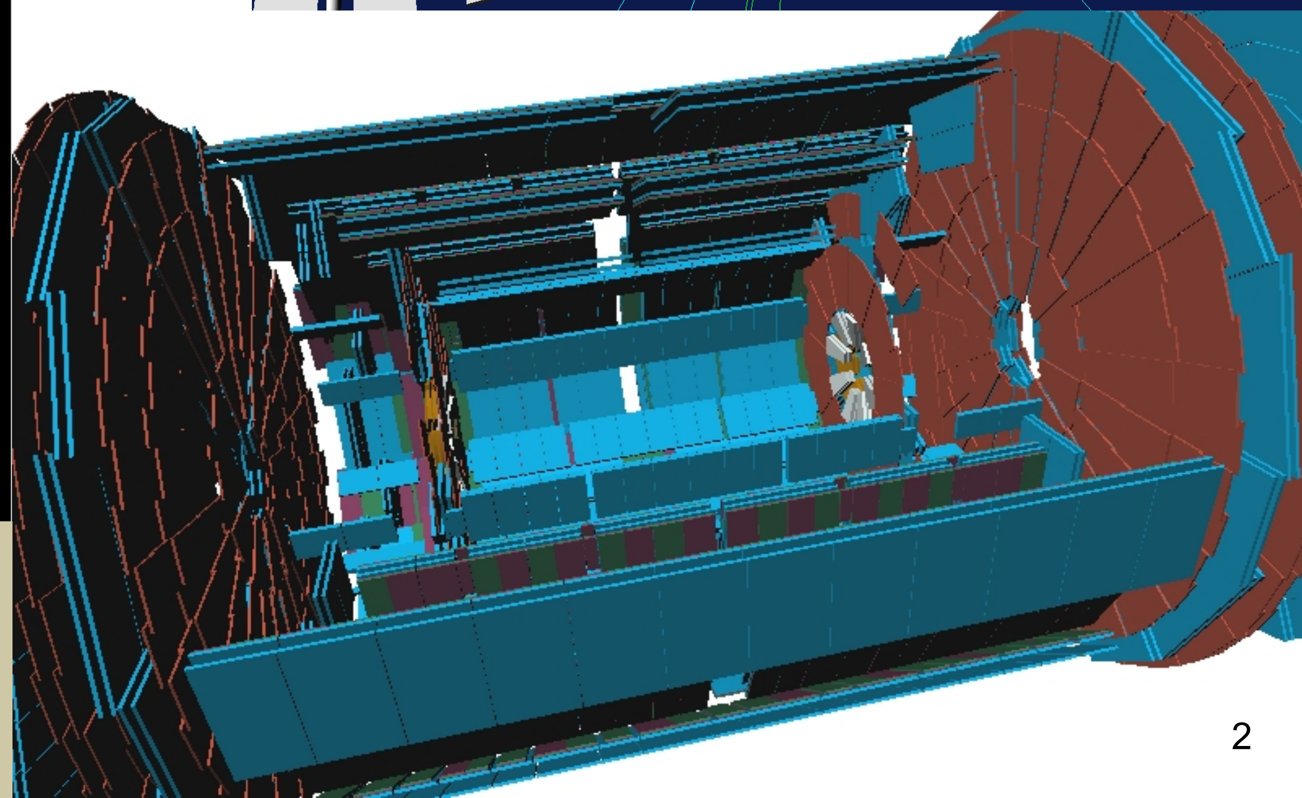
Outline



- Geant4 – now
- Geant4 – tomorrow
  : Geant4 version 10 series
- Geant4 – future
  – This talk is followed by “Geant4 on LCF” by R. Mount (SLAC)



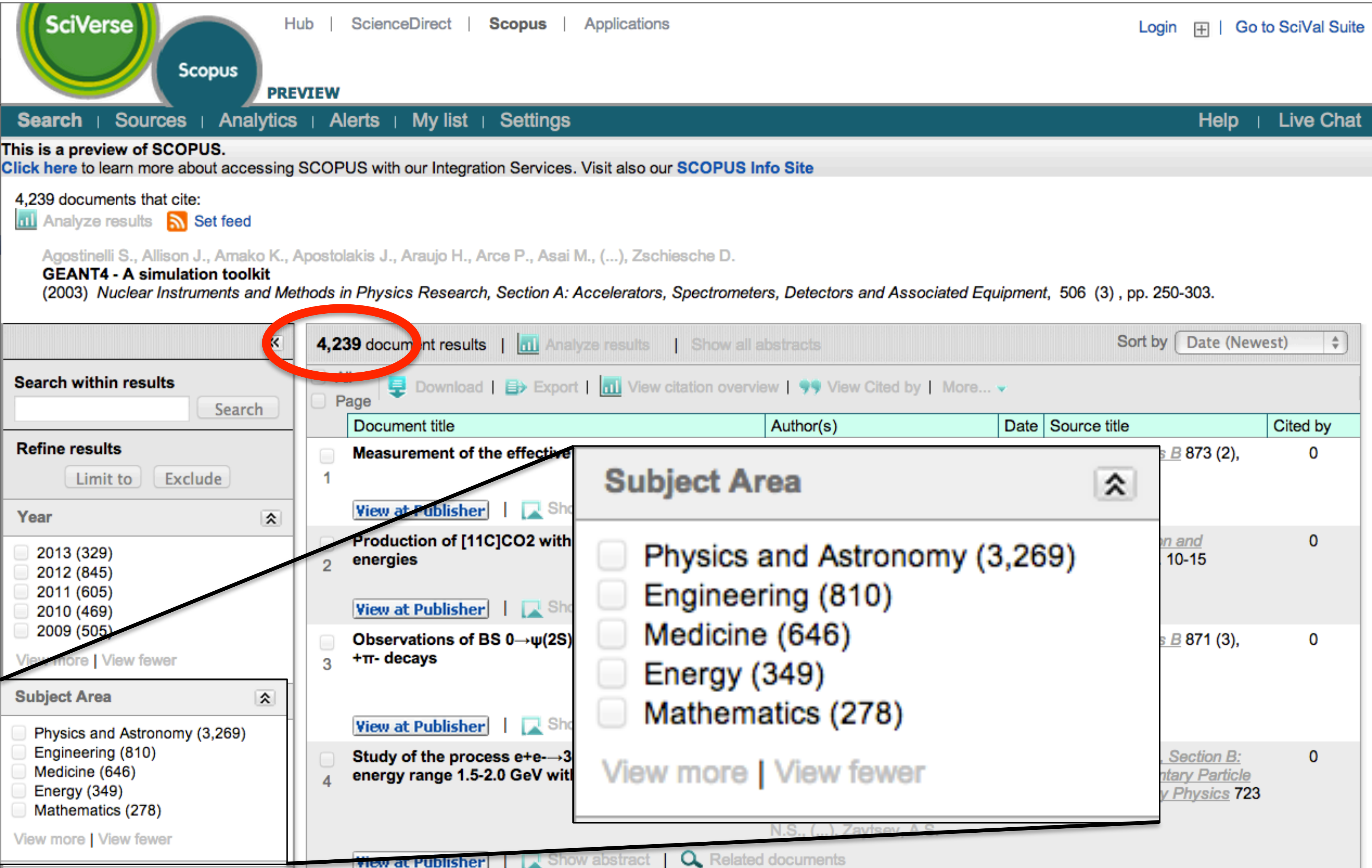




Geant4 – It's history

- Dec '94 – R&D Project start
- Apr '97 – First alpha release
- Jul '98 – First beta release
- Dec '98 – First Geant4 public release - version 1.0
- …
- Dec 2nd, '11 – Geant4 version 9.5 release
  - Oct 30th, '12 – Geant4 9.5-patch02 release
- Nov 30th, '12 – Geant4 version 9.6 release
  - May 24th, '13 – Geant4 9.6-patch02 release ← Current version
- Jun 28th, '13 – Geant4 10.0-beta release (planned)
- Dec 6th, '13 – Geant4 10.0 release (planned)

- We currently provide one public release every year.
  - Beta releases are also available.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Agostinelli S., Allison J., Amako K., Apostolakis J., Araujo H., Arce P., Asai M., (...), Zschiesche D.
GEANT4 - A simulation toolkit
(2003) Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 506 (3) , pp. 250-303.
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Geant4 is a toolkit for simulating the passage of particles through matter. It includes a complete range of functionality including tracking, geometry, physics models and hits. The physics processes offered cover a comprehensive range, including electromagnetic, ...
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Geant4 developments and applications
J Allison, K Amako, J Apostolakis… - Nuclear Science, …, 2006 - ieeexplore.ieee.org
Abstract Geant4 is a software toolkit for the simulation of the passage of particles through matter. It is used by a large number of experiments and projects in a variety of application domains, including high energy physics, astrophysics and space science, medical physics ...
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G Collaboration, S Agostinelli - Nucl. Instrum. Meth. A, 2003 - ns1.hep.scitec.kobe-u.ac.jp
Abstract GEAnT4 is a toolkit for simulating the passage of particles through matter. It includes a complete range of functionality inclu
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platform
D Strulab, G Santin, D Lazaro, V Breton… - Nuclear Physics B- …, 2003 - Elsevier
We present the development of GATE, the Geant4 Application for Tomographic Emission, as a new general purpose simulation platform for PET and SPECT applications. Built on top of
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GEANT4—a simulation toolkit
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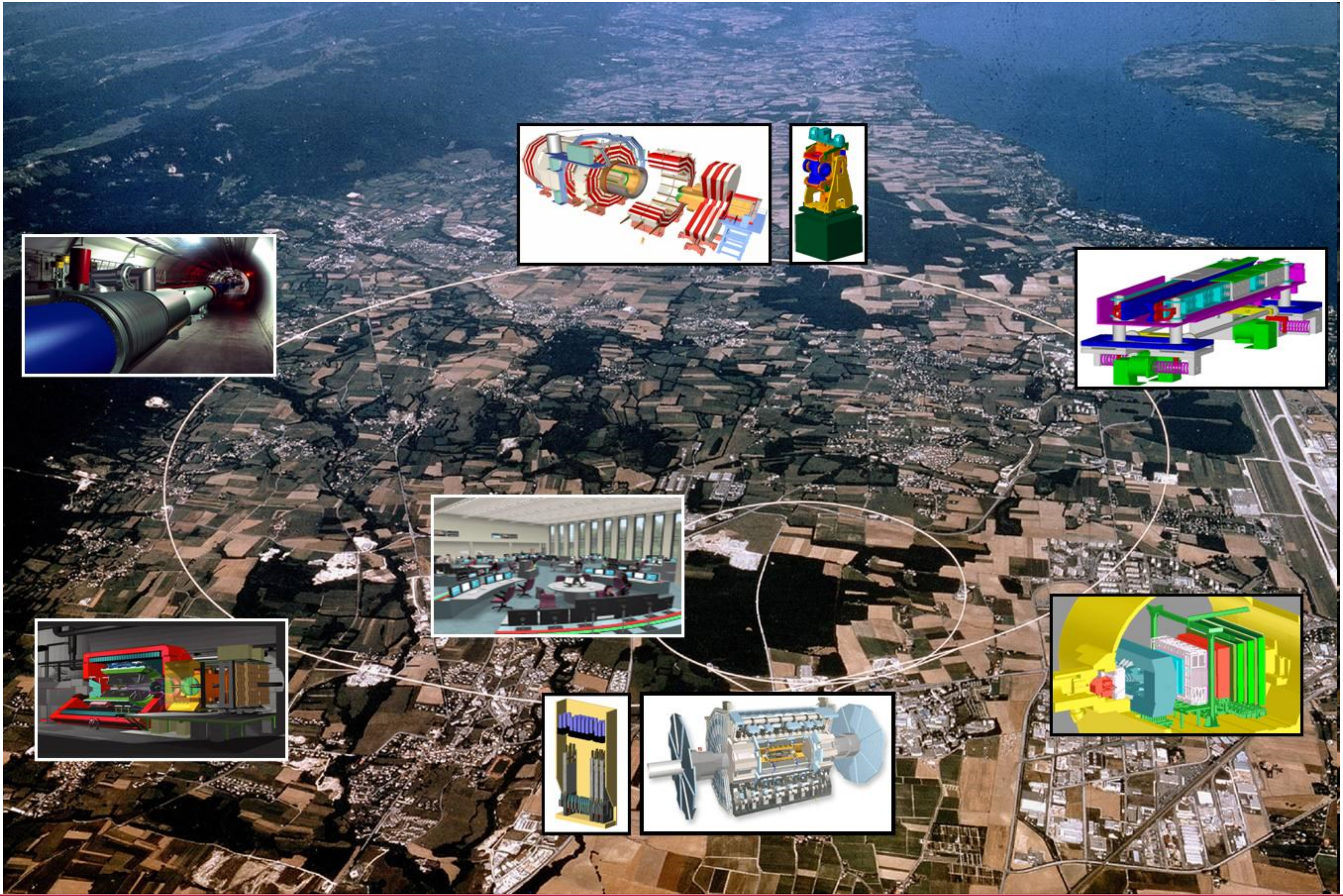
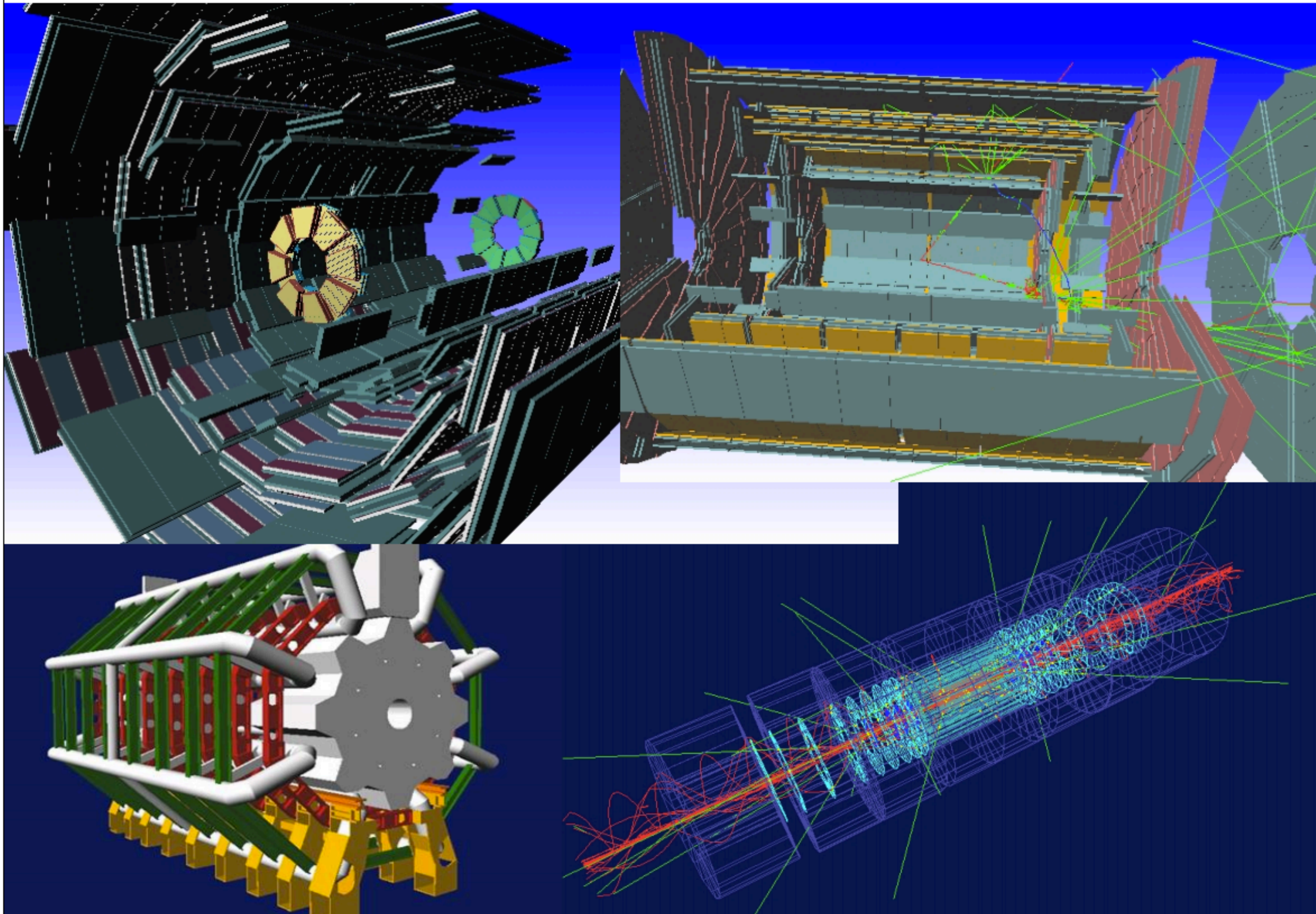
Large Hadron Collider @ CERN



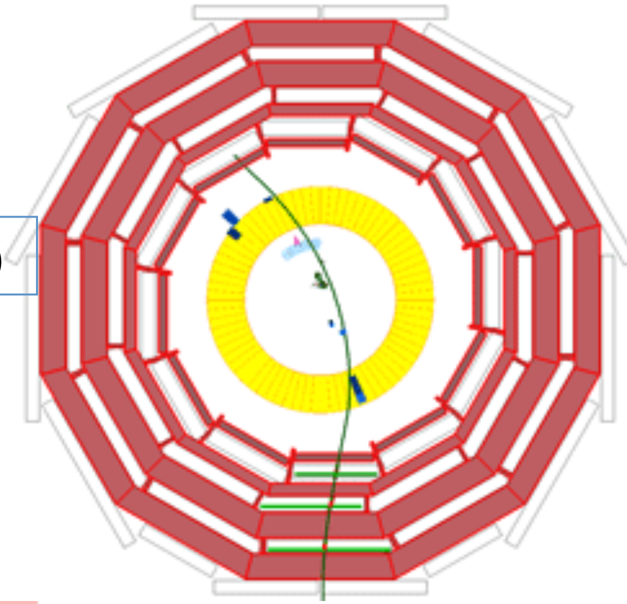
Geant4 in High Energy Physics (ATLAS at LHC)



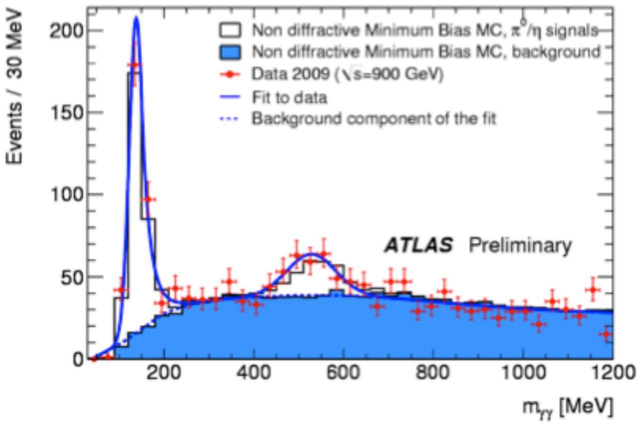
Geant4 has been successfully employed for

- Detector design
- Calibration / alignment
- First analyses

T. LeCompte (ANL)



GEANT4 Comparisons with the Calorimeters



Invariant mass of pairs of well-isolated electromagnetic clusters.

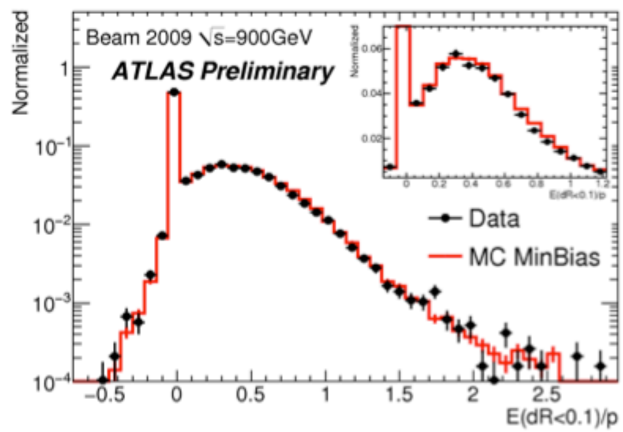
The π^0 mass is within 0.8 ± 0.6% of expectations.

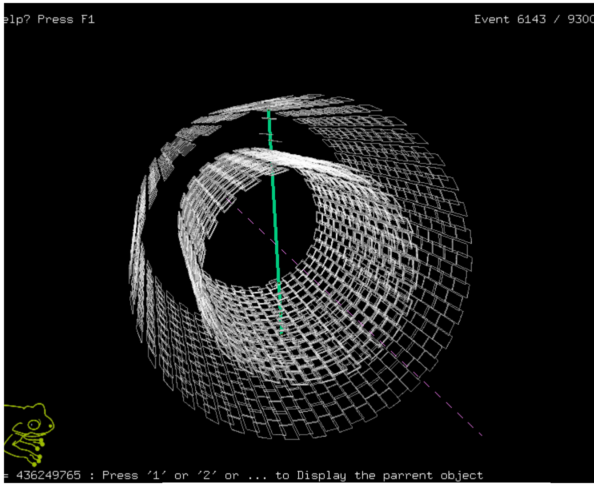
The η^0 mass is within 3 ± 2% of expectations.

The detector uniformity is better than 2%.

Response of the calorimeter to single isolated tracks. To reduce the effect of noise, topological clusters are used in summing the energy.

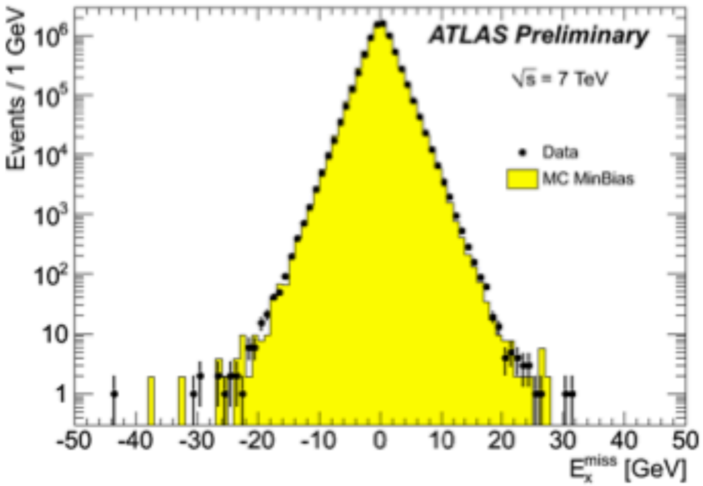
This plot agreed better than we ever expected. (I sent the student who made it back to make sure that they didn't accidentally compare G4 with G4.

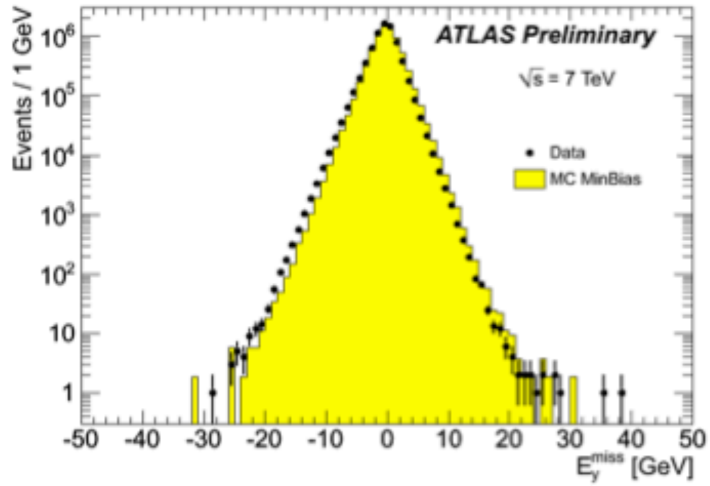




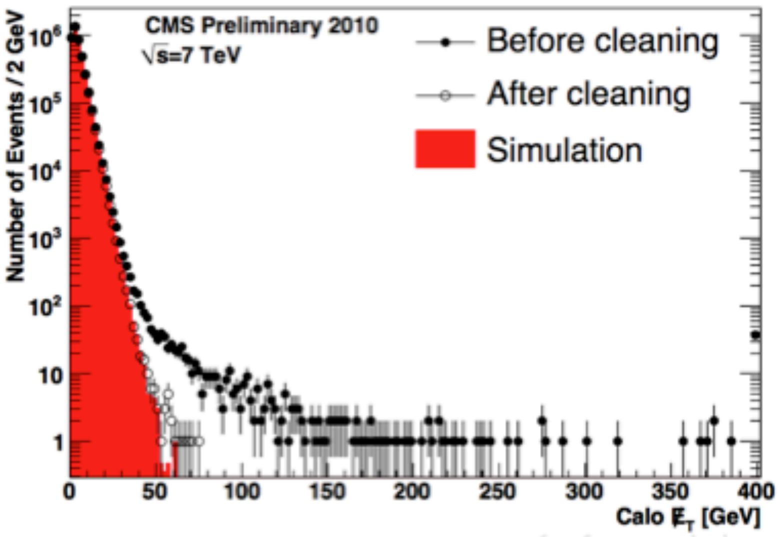
Figures from CMS

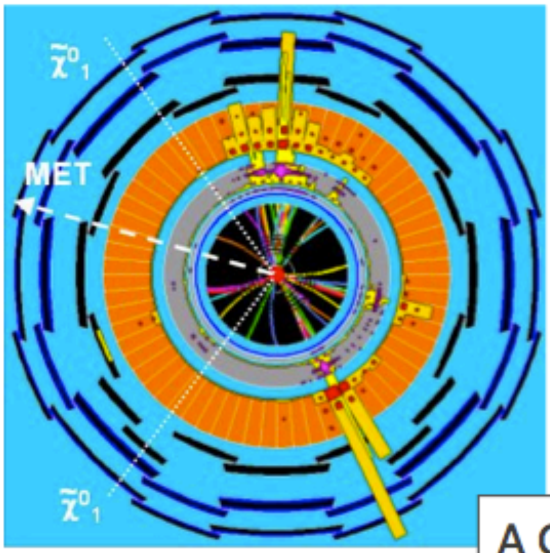
Missing E_T





This is one of the hardest things to get right. MET incorporates everything measured in the detector and attempts to identify non-interacting particles, such as neutrinos or dark matter.





A GEANT4 event.

Agreement is astounding.

You can even see that the ATLAS detector is not quite centered – in both data and MC.

Both ATLAS and CMS plots are made from a tiny piece of the very earliest data.

T. LeCompte (ANL)

Beam transport for Project X

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Muons, Inc.

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G4BEAMLINE

A "Swiss Army Knife" for Geant4, optimized for simulating beamlines.

Getting Started | Documentation | Download | Support | Example | Forum | Doxygen | New Feature Requests

HistoRoot has been separated from G4beamline, and is a separate application available here.

The advantage is that HistoRoot is now compiled, and runs ~100 times faster on large files.

The G4beamline validation document is now available here.

G4beamline 2.12 is now available here.

The G4beamline User's Guide is available here.

G4beamline now supports the making of movies

Here is a Flash movie of Example1: Movie. This example is just a gaussian beam expanding in free space (the 4 virtualdetectors are not visible). Muons are blue and a handful of decay electrons and neutrinos are red and gray. This 10 second movie took 12 seconds of CPU time to produce.

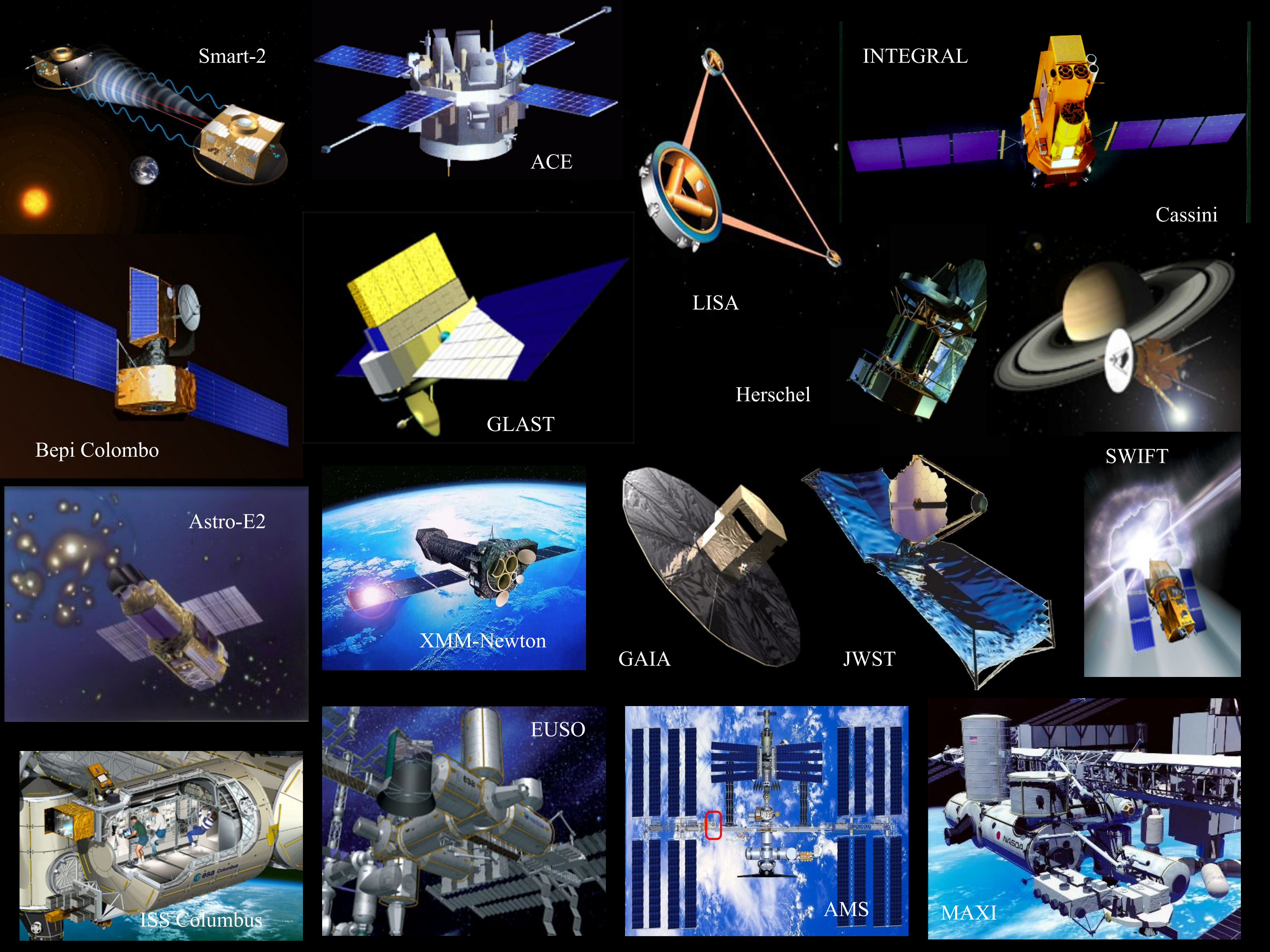
The G4beamline Tutorial given at LEMC 2008 was videotaped by Fermilab Visual Media Services. part 1 part 2

Click here for a Flash video giving a screencast of using G4beamline for a simple example.

General

G4beamline is a single-particle tracking program based on the Geant4 simulation toolkit. It is specifically designed for the simulation of beamlines.

The key aspect of g4beamline is that the input file defining the simulation is not significantly more complicated than the problem being simulated (by contrast, any C++ simulation program will inherently be significantly more complicated than the problem) — G4beamline isolates the user from programming complexities. To make this possible, g4beamline does not give the user all of the power and flexibility of the underlying Geant4 toolkit; it does, however, provide enough flexibility to simulate many different systems that can be considered "beamlines" one way or another. For instance, there is a "cosmic-ray beam", and the notion of "beamline" is rather flexible. In use, one normally just lays out the beamline elements along the beam centerline, using "centerline coordinates" that rotate appropriately whenever needed (e.g. when a bending magnet is placed, or at a target to take a secondary beam off at an angle).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INTEGRAL
Cassini
GLAST
Herschel
Bepi Colombo
SWIFT
Astro-E2
XMM-Newton
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Public webs

TWiki > AMS Web > AMSSoftware > AmsGeant4 (10-Jul-2012, ZhiliWeng)

Edit Attach

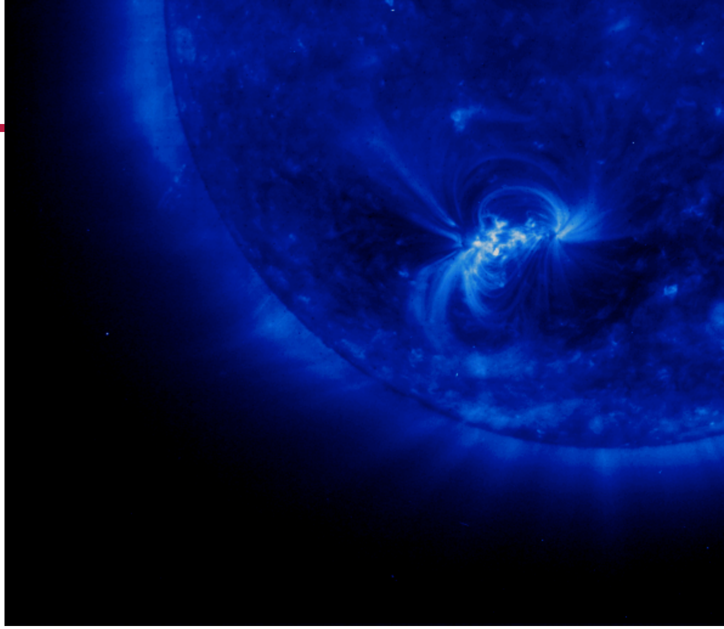
GEANT4 in AMS

- **The official simulation of the AMS detector is based on GEANT4**
- **The AMS-GEANT4 in use is a customization of the version:** 4.9.3.p02 (tarball)
- The AMS patch for GEANT4 is available here: geant4.9.3.p02-AMSpatch

The AMS Customizations to GEANT4 are summarized in the following

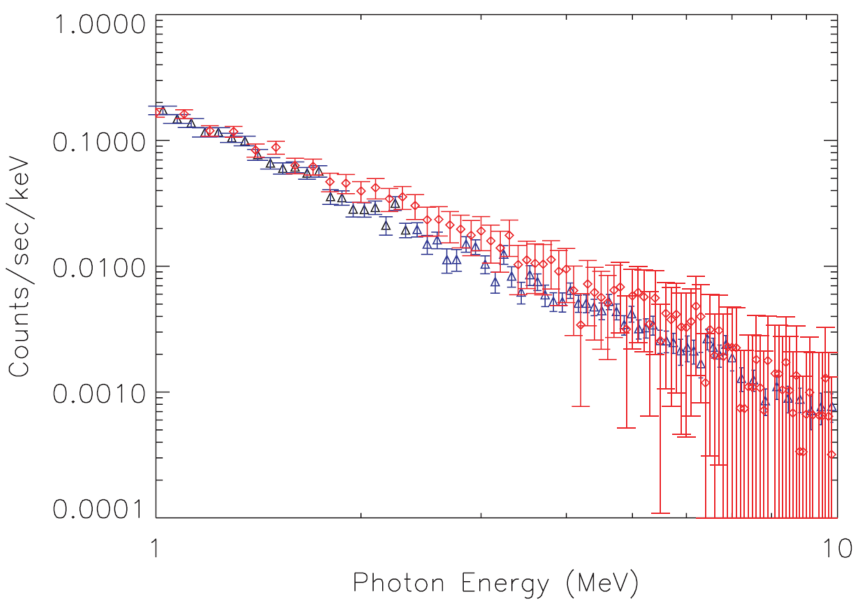
- ### Compilation Fixes
  - file config/sys/Linux-g++.gmk
  - file config/sys/Linux-icc.ia64.g
- ### Remove PrintOut
  - file source/event/src/G4Partic
  - Some G4 printout is removed
  - Modified to allow changing of
- ### Add Accessors and Setter
  - file source/geometry/manager
  - file source/geometry/manager
  - file source/geometry/volumes/
  - Some service members and t

Solar event gamma-rays



- Electron Bremsstrahlung – induced gammas in solar flares
- Compton back-scattering

  → observable gamma-ray spectrum much softer than predicted by simple analytic calculations



Effects of Compton scattering on the Gamma Ray Spectra of Solar flares

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Department of Physics, University of Tokyo, Bunkyo-ku, Tokyo, 113-0022

and

Mitsuhiro Kohama, Yukikatsu Terada and Toru Tamagawa

RIKEN (Institute of Physical and Chemical research), Wako-shi, Saitama

[1] *Also at RIKEN*

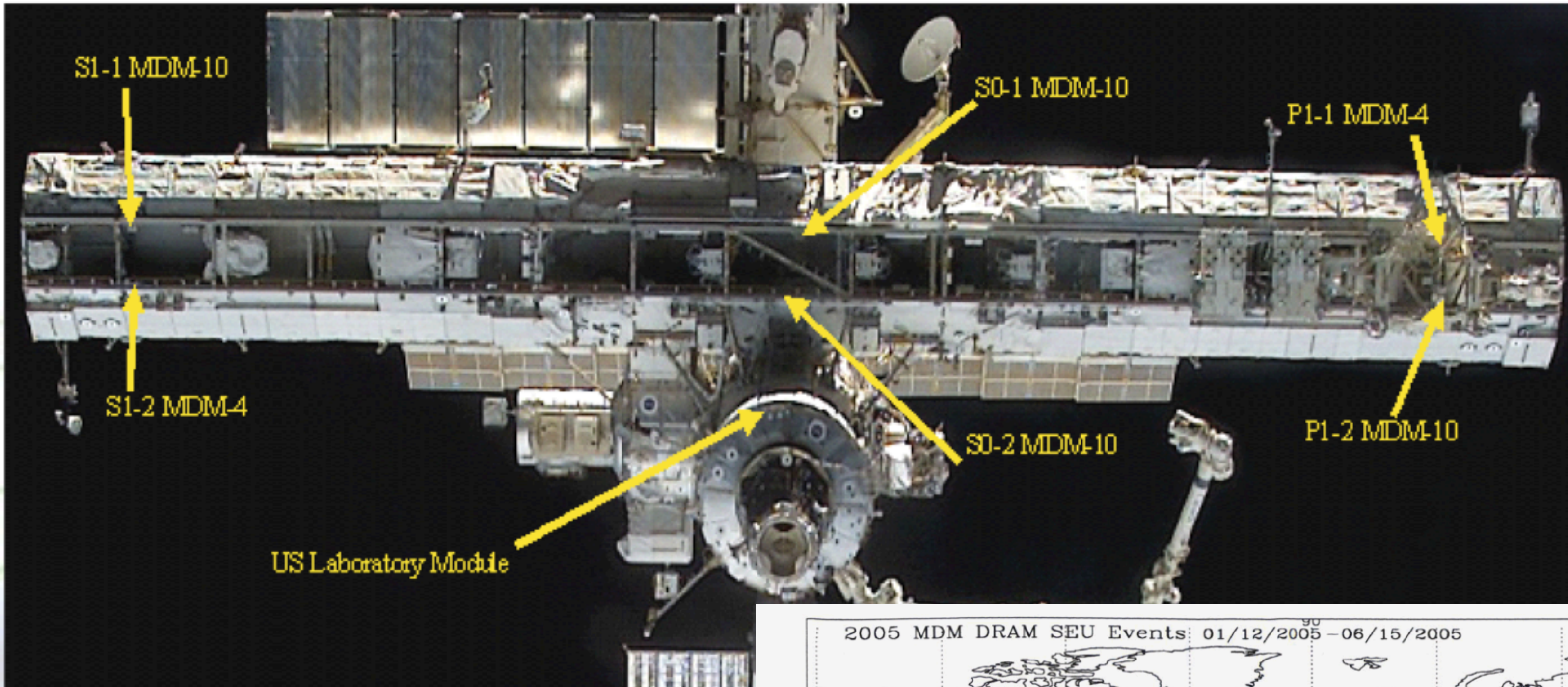
[2] *Present address: Mitsubishi Electric Co., Ltd.*

(Received ; accepted)

Abstract

Using fully relativistic GEANT4 simulation tool kit, the transport of energetic electrons generated in solar flares was Monte-Carlo simulated, and resultant bremsstrahlung gamma-ray spectra were calculated. The solar atmosphere was ap-

Single Event Upset on SRAM in space radiation environment



MDM: Median Shielding (Fig.1)	On-orbit SEU Count SEU/238 days)
Lab-1: 40 g/cm^2	**488 ± 22**
Lab-3: 40 g/cm^2	**490 ± 22**
P1-2: 10g/cm^2	**536 ± 23**
S1-1: 10g/cm^2	**488 ± 22**

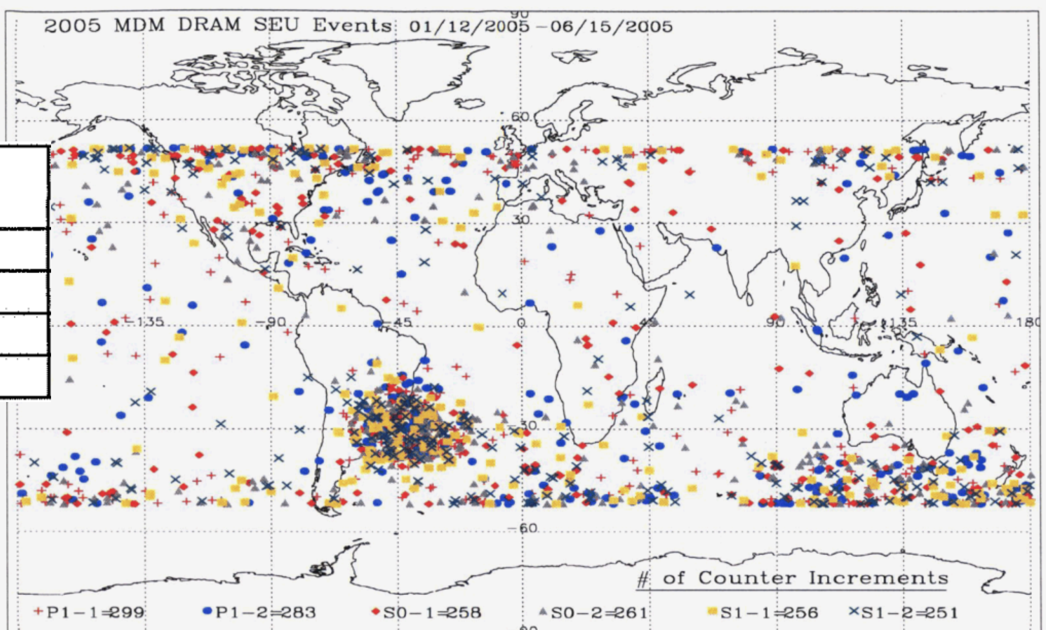
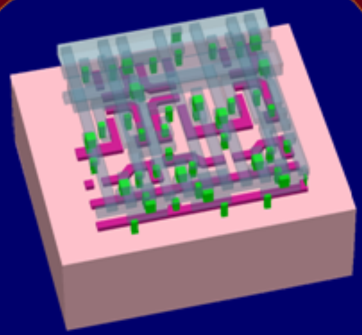
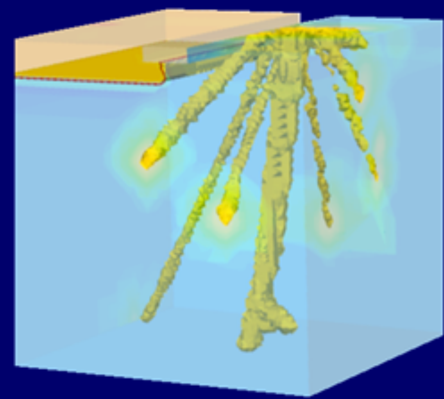


Figure 4: Aggregate ISS External MDM DRAM SEU Map; 155 days calendar time with 135 days data acquisition time after accounting for loss-of-signal (LOS) periods

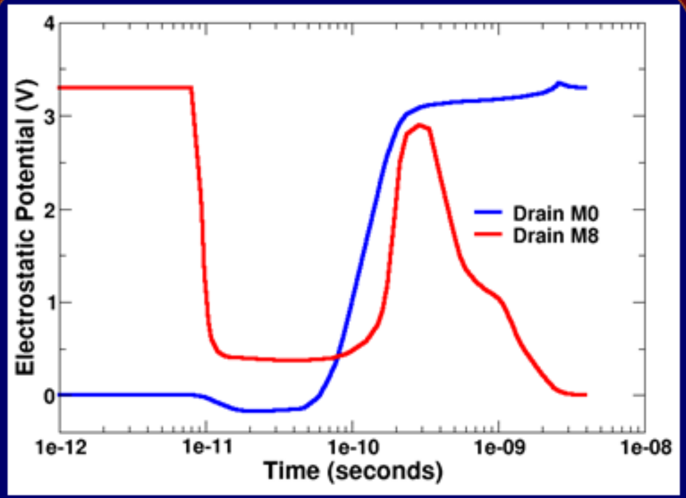
RADSAFE on SEE in SRAMs



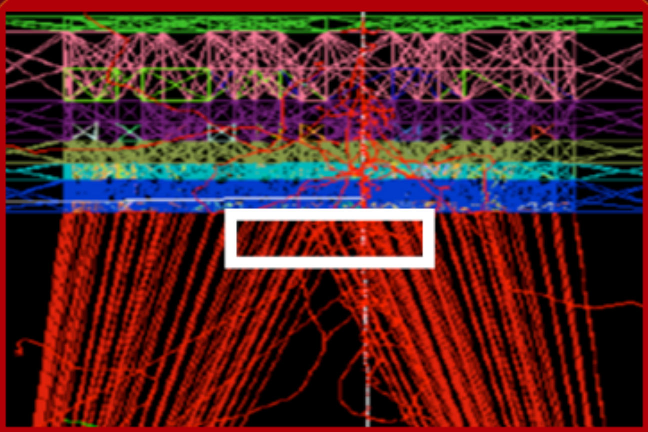
TCAD Cell Structure: SRAM Cell



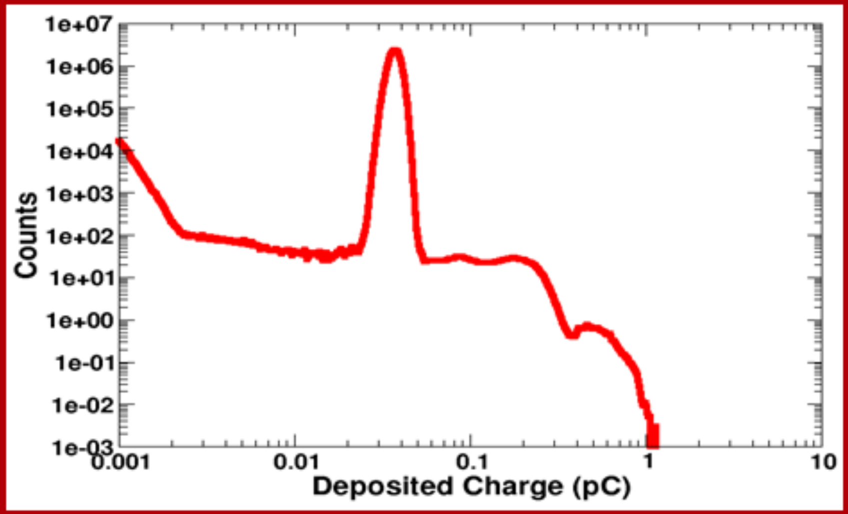
Single Charge Deposition in TCAD: Ne+W Event



SRAM Cell Upset



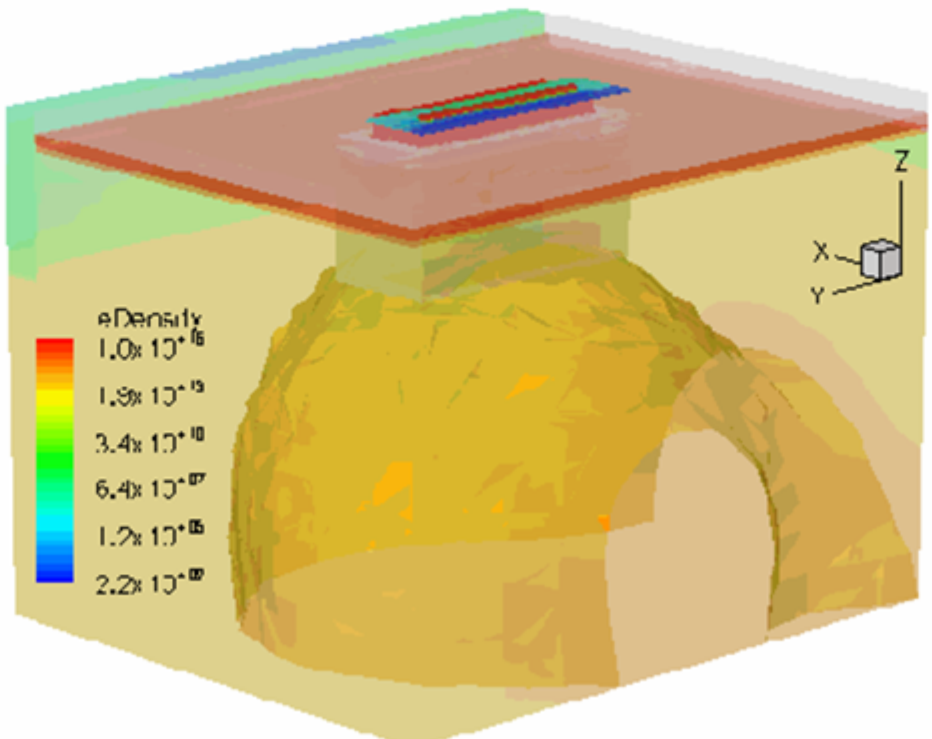
Geant4 Geometry and 523 MeV Neon Event



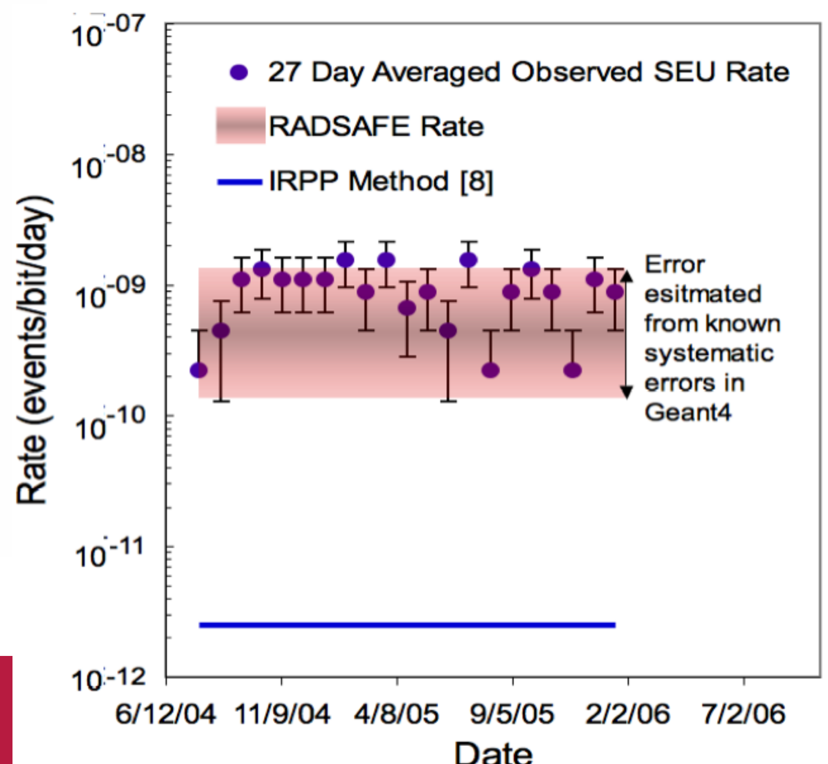
MRED Energy Deposition for 10^8 Events

Simulation of Single Event Effect

- 63-MeV proton incident on a SiGe Heterojunction Bipolar Transistor (HBT)
- Iso-charge surfaces following a nuclear reaction

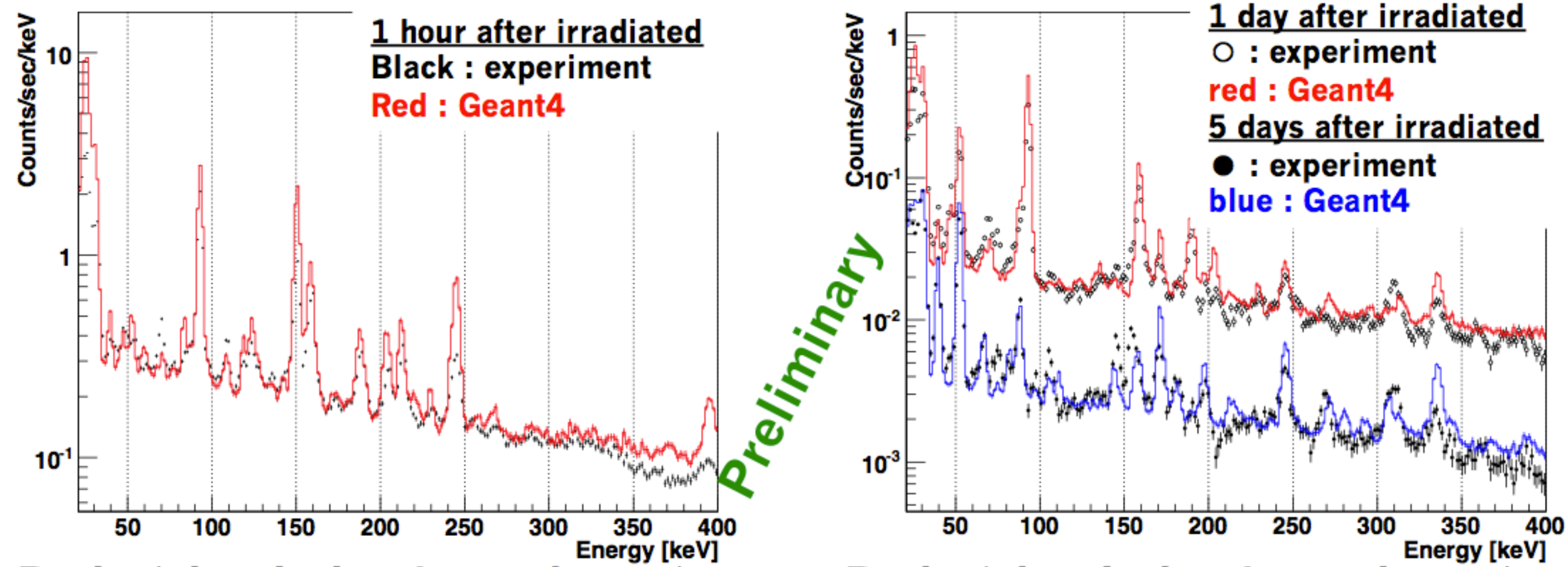


- SRAM used on NASA spacecraft observed Average SEU Rate:
  - 1×10^{-9} Events/Bit/Day
- Vendor predicted rate using CREME96:
  - 2×10^{-12}
- Geant4-based MRED rate (includes reaction products):
  - Between 1.3×10^{-10} and 1.3×10^{-9}

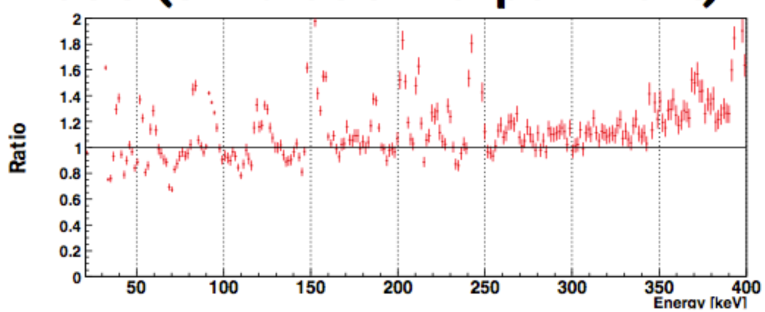


Time evolution of the activation background

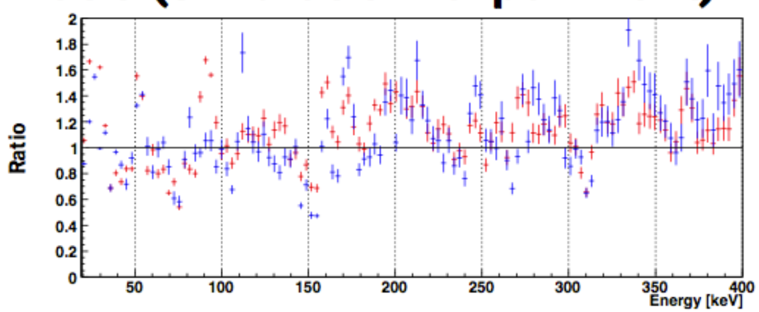
Comparison with Geant4



Ratio (simulation/experiment)

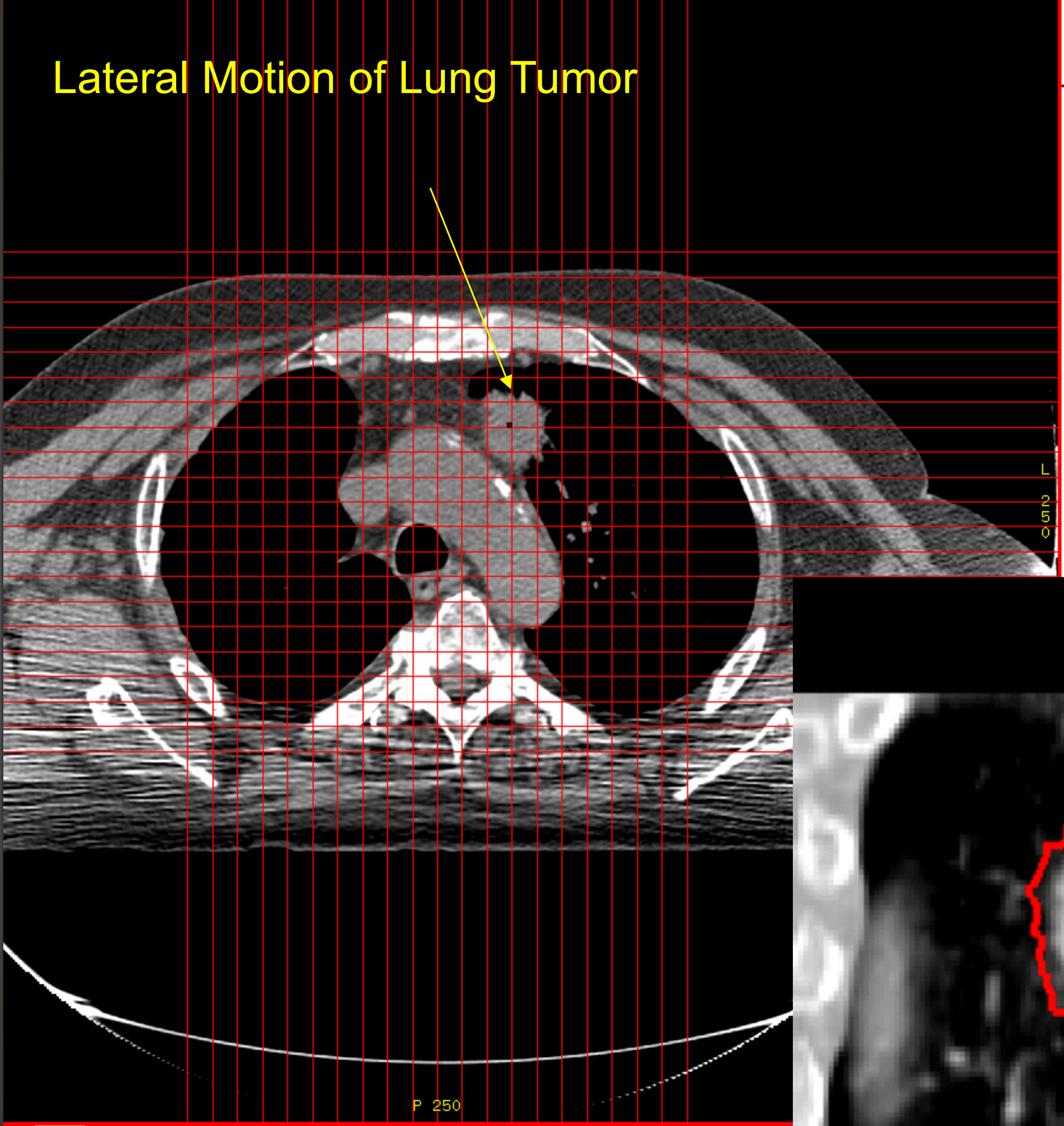


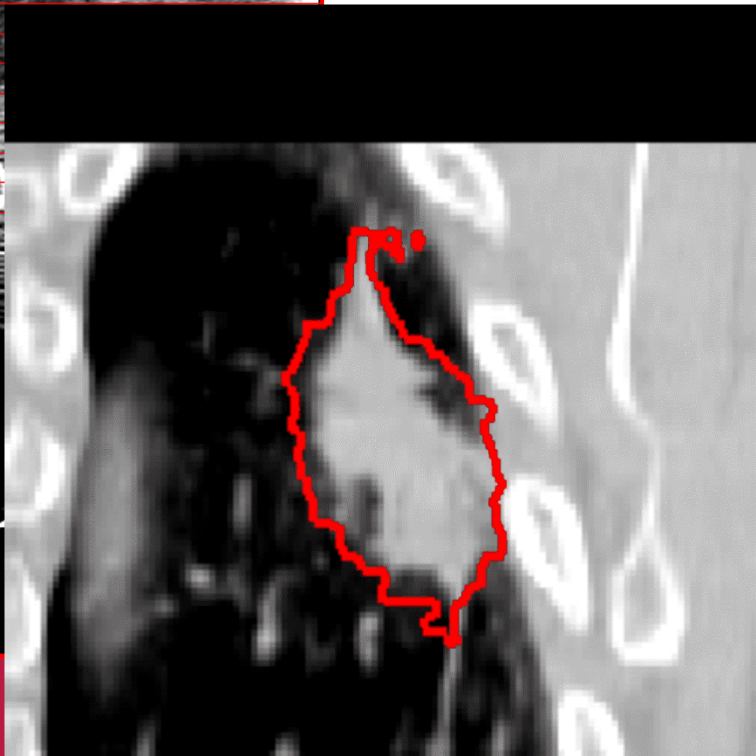
Ratio (simulation/experiment)

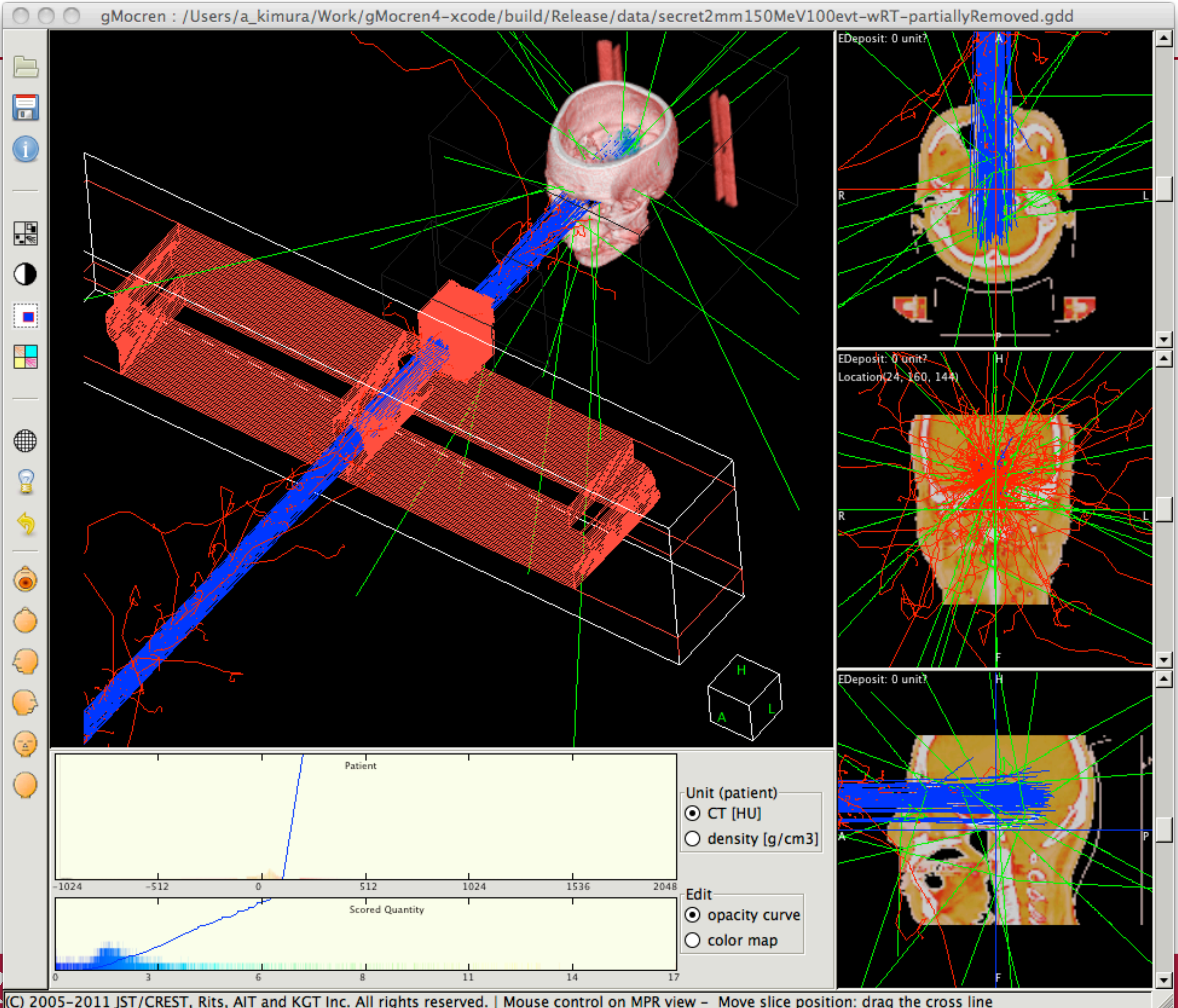


❖ Simulation results agrees with experimental data within a factor of two in terms of the line intensities

Lateral Motion of Lung Tumor



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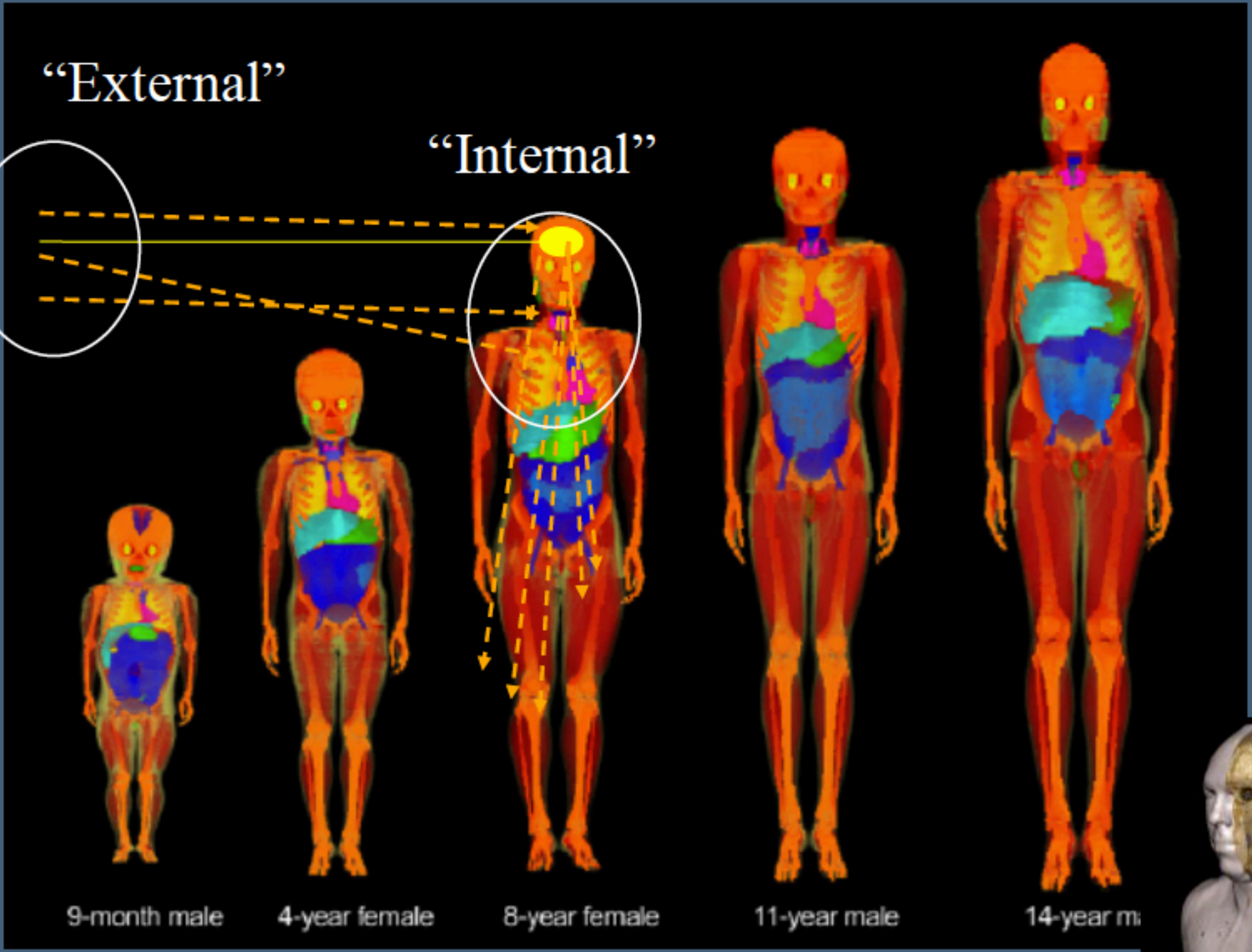
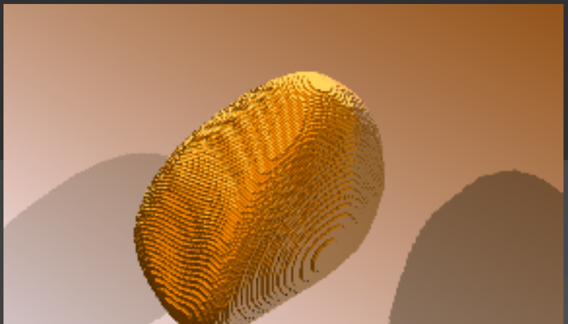
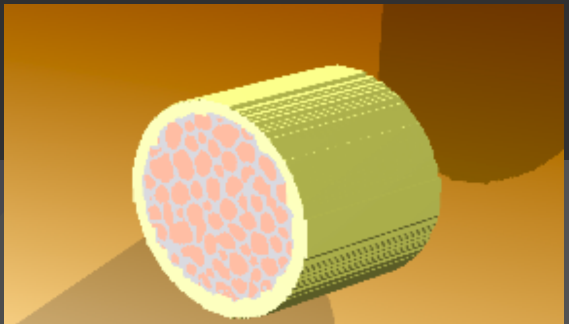


Phantoms implemented into the Geant4 Monte Carlo dose calculation environment at Mass. Gen. Hosp.

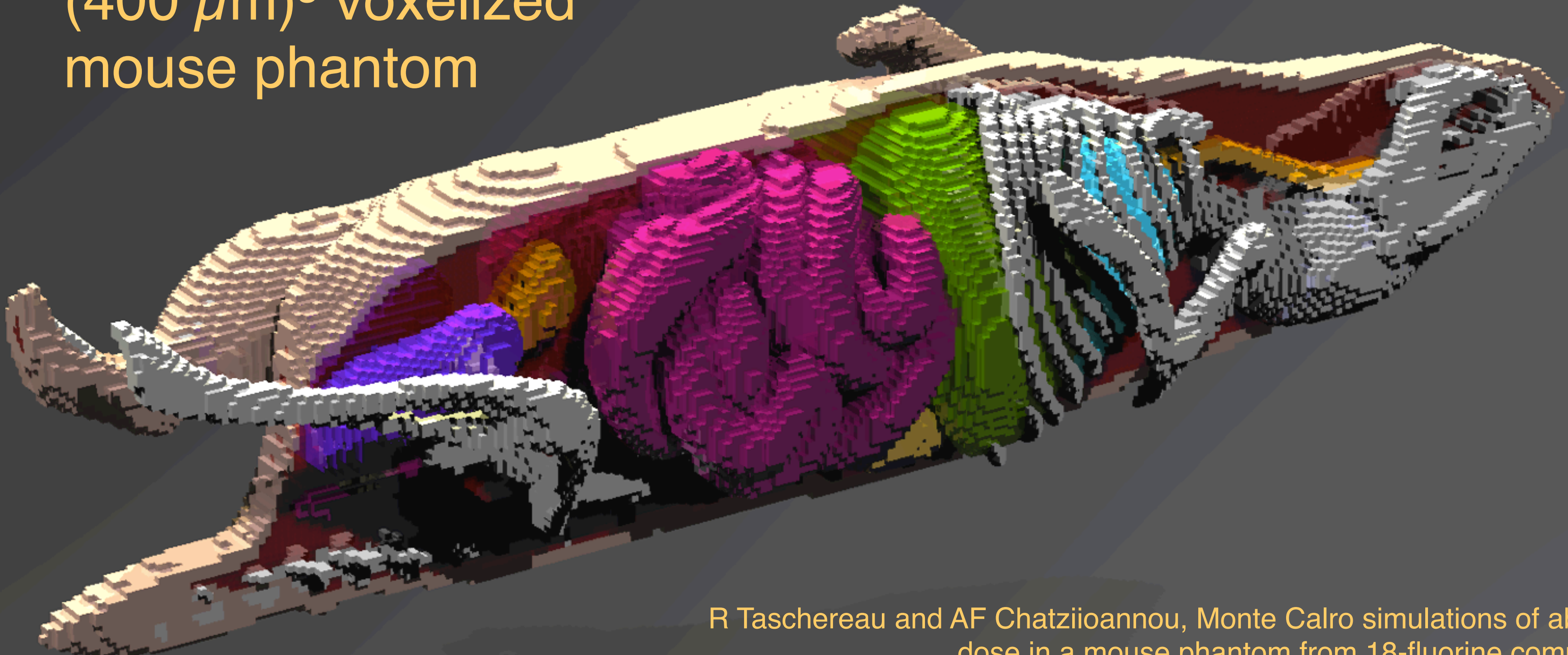
High resolution phantoms


Vertebra (25 μm)^3


Bladder (50 μm)^3

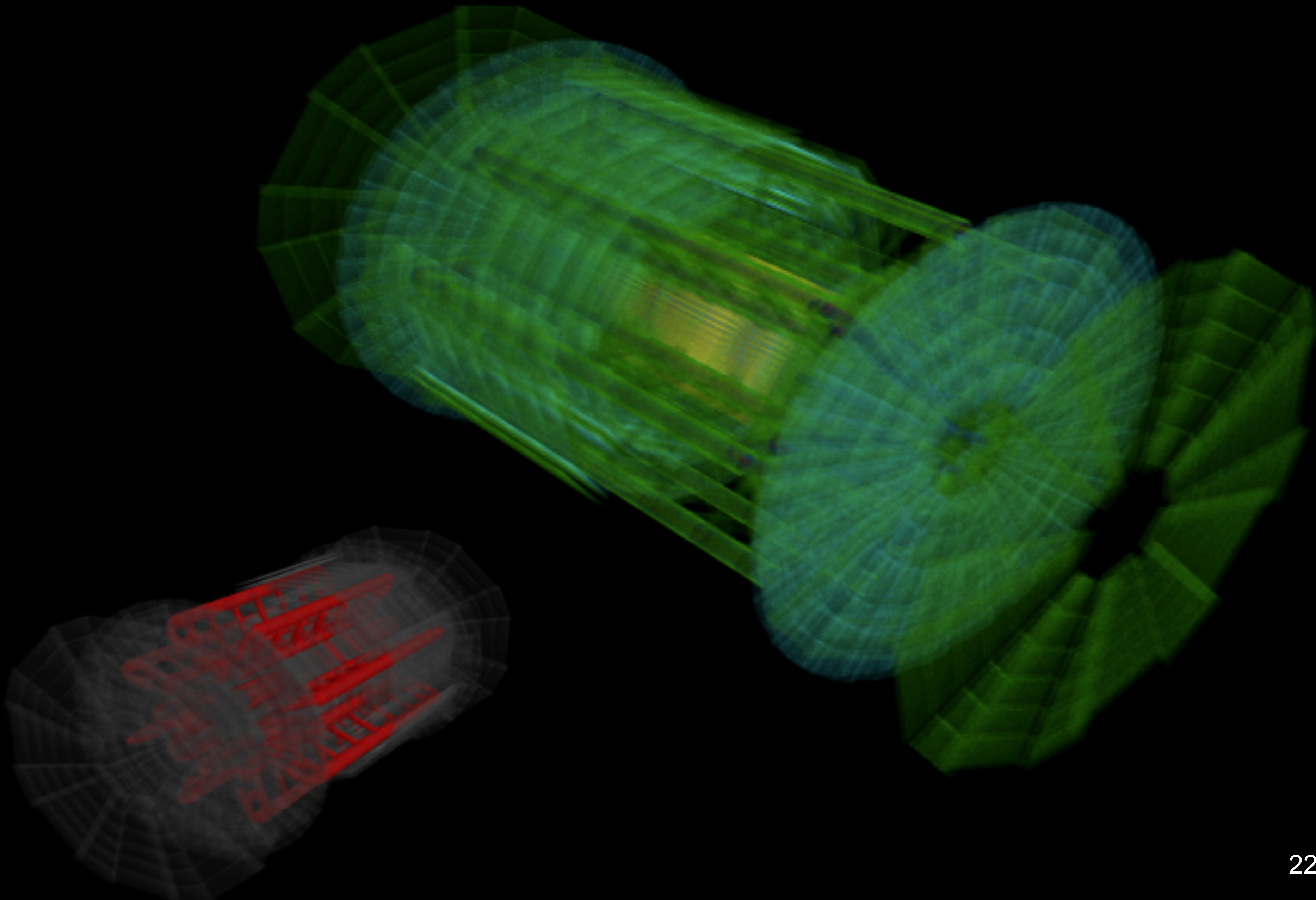

Trabecular bone (15 μm)^3

(400 μm)^3 voxelized mouse phantom



R Taschereau and AF Chatziioannou, Monte Calro simulations of absorbed dose in a mouse phantom from 18-fluorine compounds, Medical Physics, 34(3), 1026-36 (2007)

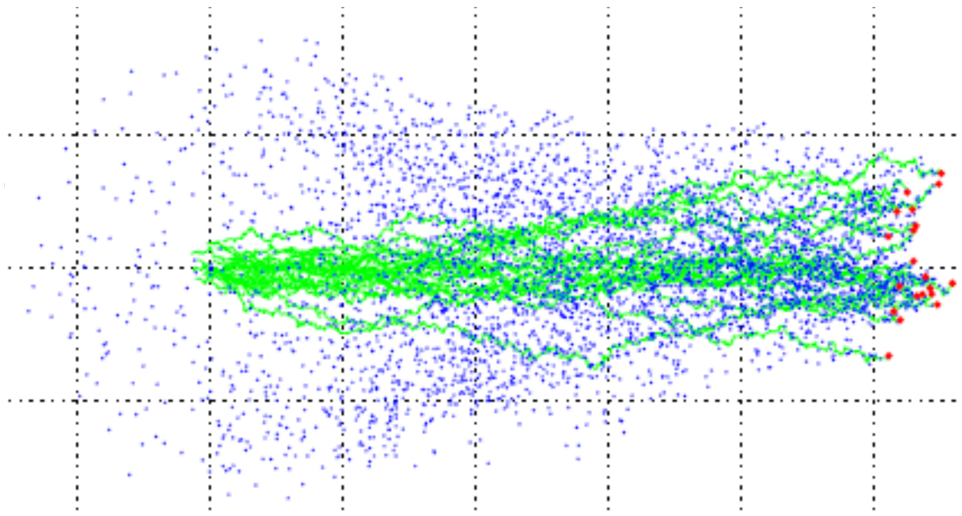
New high-resolution transparent visualization

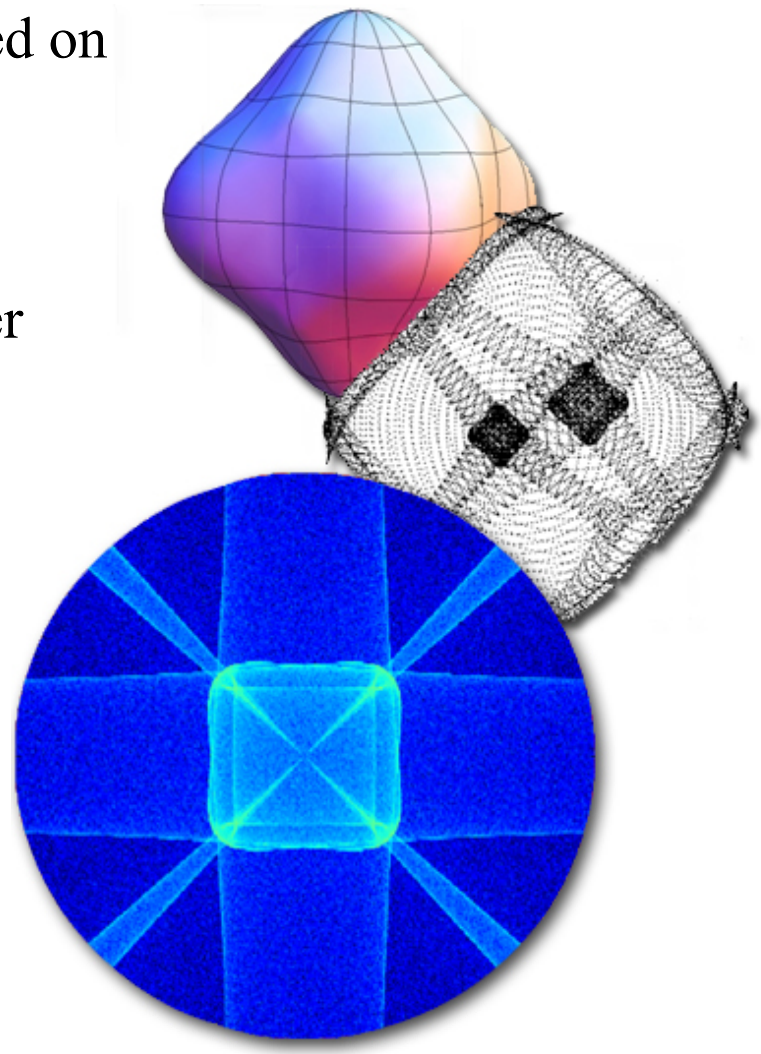


Condensed Matter Physics in Geant4

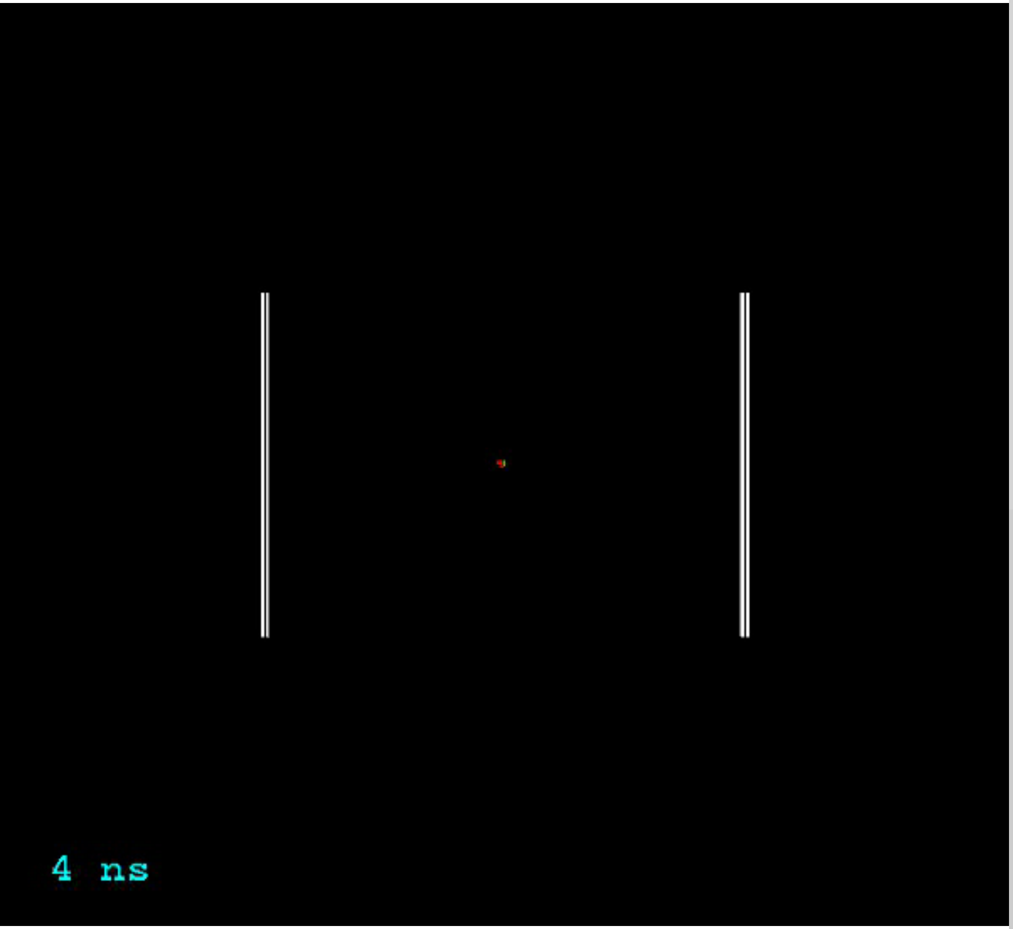
•Phonon propagation, including focusing based on elasticity tensor (right)

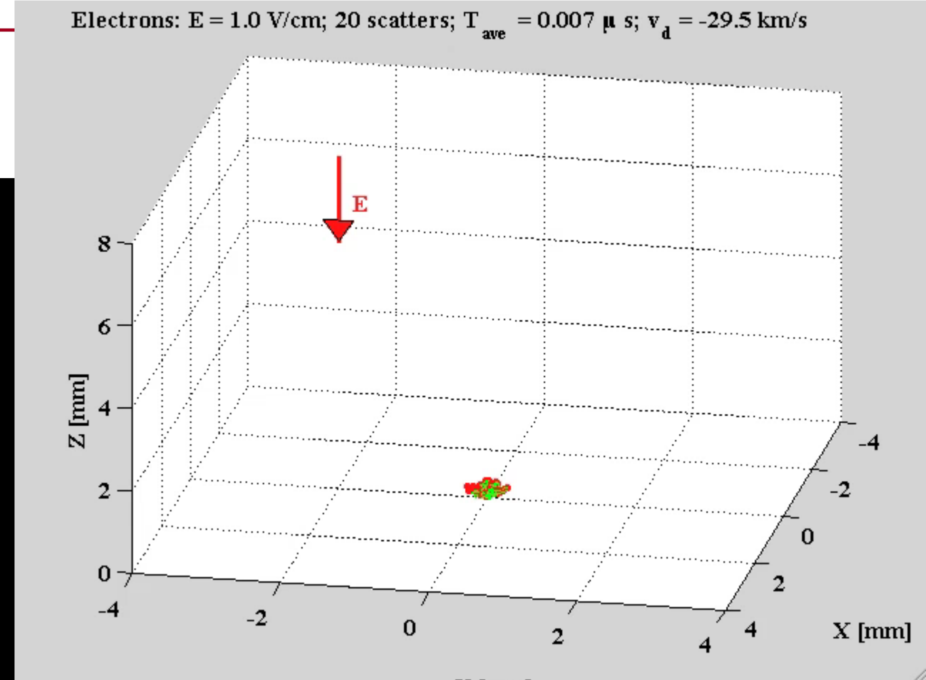
•e-/h+ transport, including conduction band anisotropy and Luke-Neganov emission, under development (below)

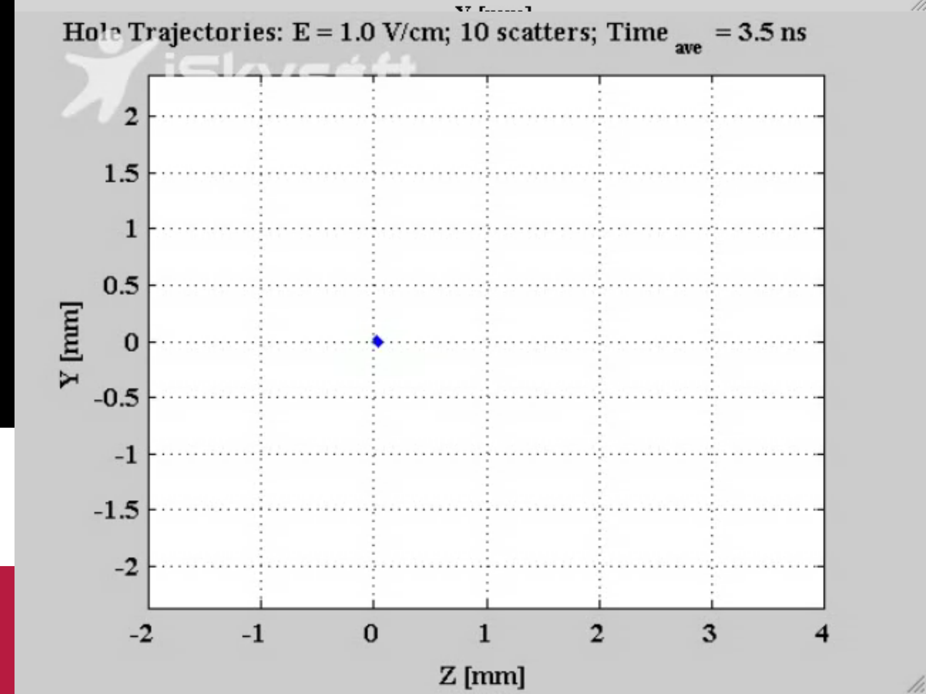




e-/h propagation with Luke phonon emission in Ge crystal



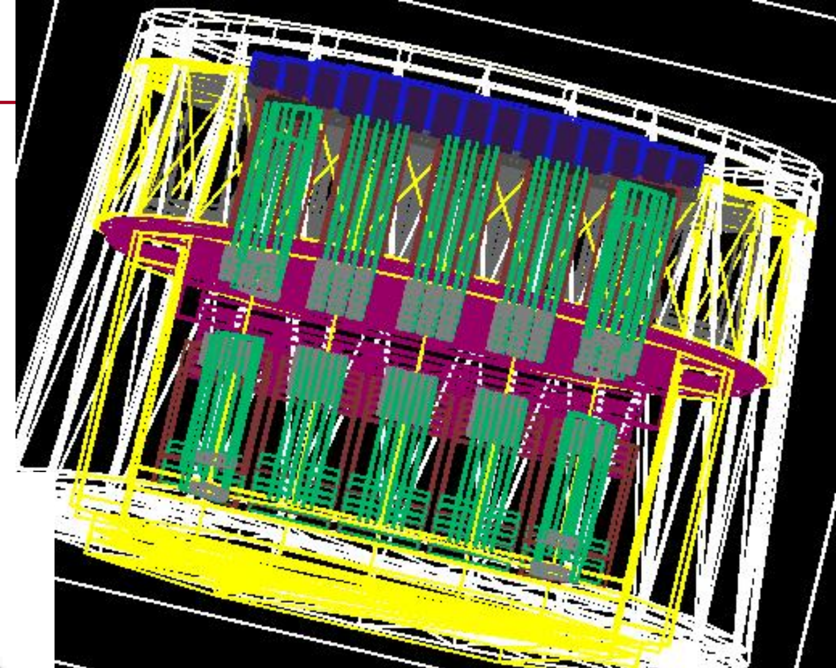


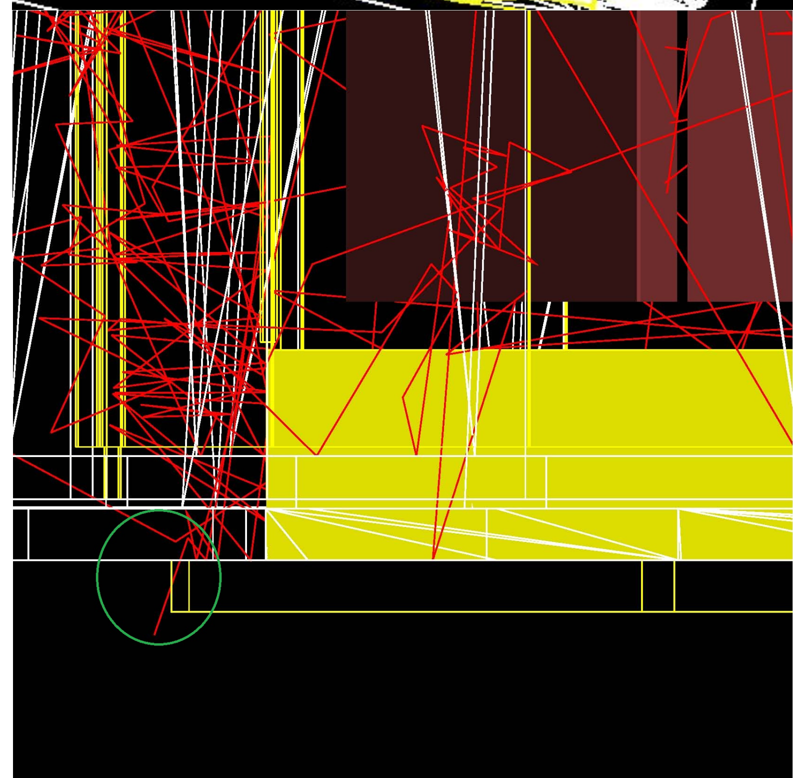


SLAC

Extending Geant4 coverage

- Phonon transport in cryogenic crystal
- Electron / hole transport in semiconductor
- Channeling effect in atomic lattice
- Raman scattering
- Thermal motion of atoms in vacuum cryostat





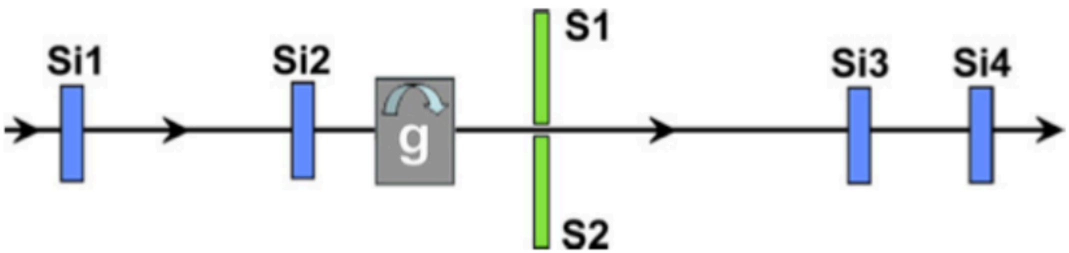
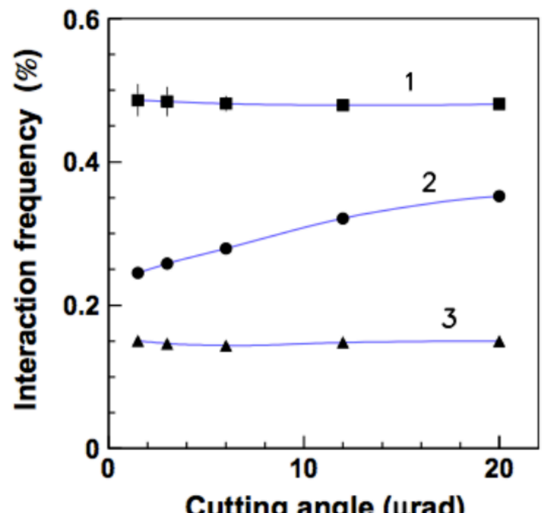


Fig. 2. Experimental layout at the external beam H8 of the CERN SPS. Here Si1–Si4 are the silicon microstrip detectors, *g* is the goniometer with a bent crystal. S1 and S2 are the scintillation detectors.



Geant4 version 10 series

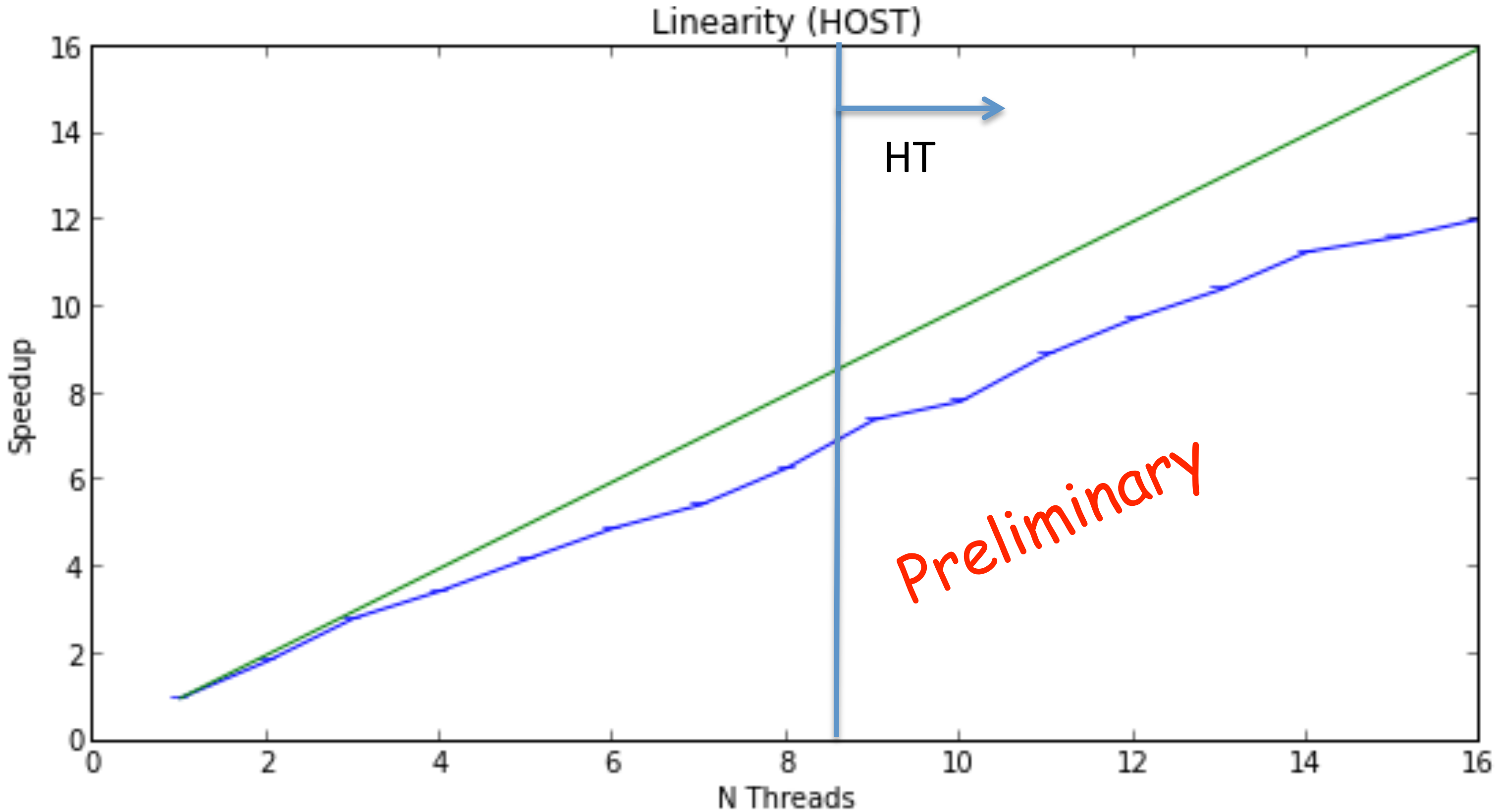
- The release in 2013 will be a major release.
  - Geant4 version 10 – planned release date : Dec. 6, 2013
- The highlight is its multi-threading capability.
  - A few interfaces need to be changed due to multi-threading
- It offers two build options.
  - Multi-threaded mode (including single thread)
  - Sequential mode
    - In case a user depends on thread-unsafe external libraries, he may install Geant4 in sequential mode.

G4MT prototype-9.4 (2011)	G4MT prototype-9.5 (2012)	G4 10.0.beta (now)	G4 10.0 (Dec. 2013)	G4 10 series (2014~)
• Proof of principle • Identify objects to be shared • First testing	• MT code integrated into G4	• API re-design • Example migration • Further testing • First optimizations	• Production ready • Public release	• Further refinements

Geant4 multi-threading : event-level parallelism

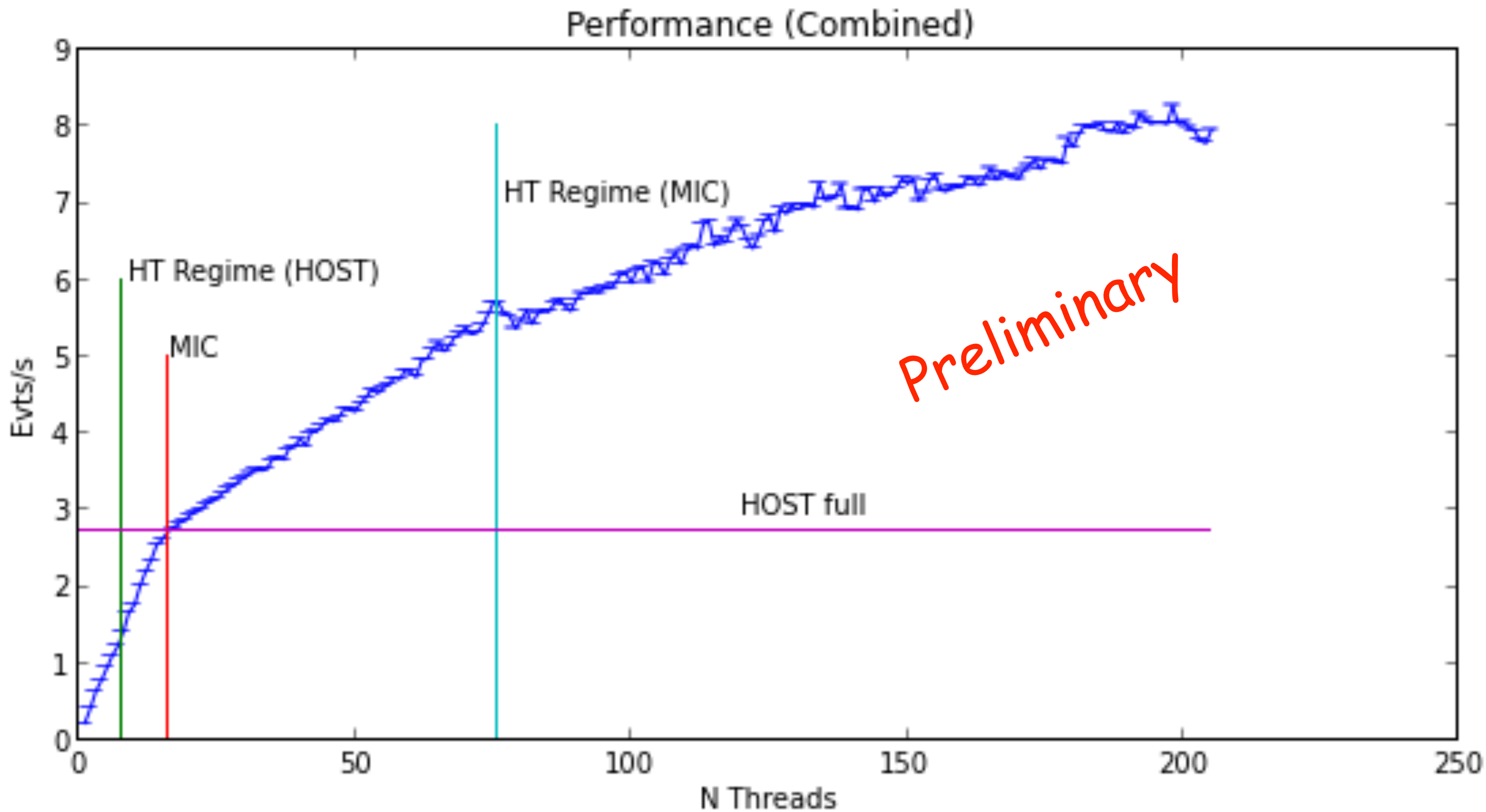
- This choice minimizes the changes in user-code
  - Maintain API changes at minimum
- All Geant4 code has been made thread-safe.
  - Thread-safety implemented via Thread Local Storage
- Most memory-consuming parts of the code (geometry, physics tables) are shared over threads.
  - "Split-class" mechanism: reduce memory consumption
    - Read-only part of most memory consuming classes are shared
    - Enabling threads to write to thread-local part
- Particular attention to create "lock-free" code: linearity (w.r.t. #threads) is the metrics we are concentrating on for the time being.
- Initial performance penalties observed in early prototypes have already been addressed.
- Testing on both x86_64 and MIC architectures
- Use of POSIX standards
  - Allowing for integration with user-preferred parallelization frameworks (e.g. MPI, TBB, etc.)

x86_64 results



- Good linearity demonstrated
  - Efficiency w.r.t. perfect linearity 90% (80% in HT)
- Out-of-the box Geant4 with MT=ON
- Further improvements expected
  - Use of lock-free malloc library and reduction of false cache should improve performance further
- See *Euro-Par2010, Part II* LNCS6272, pp.287-303: full efficiency recovered

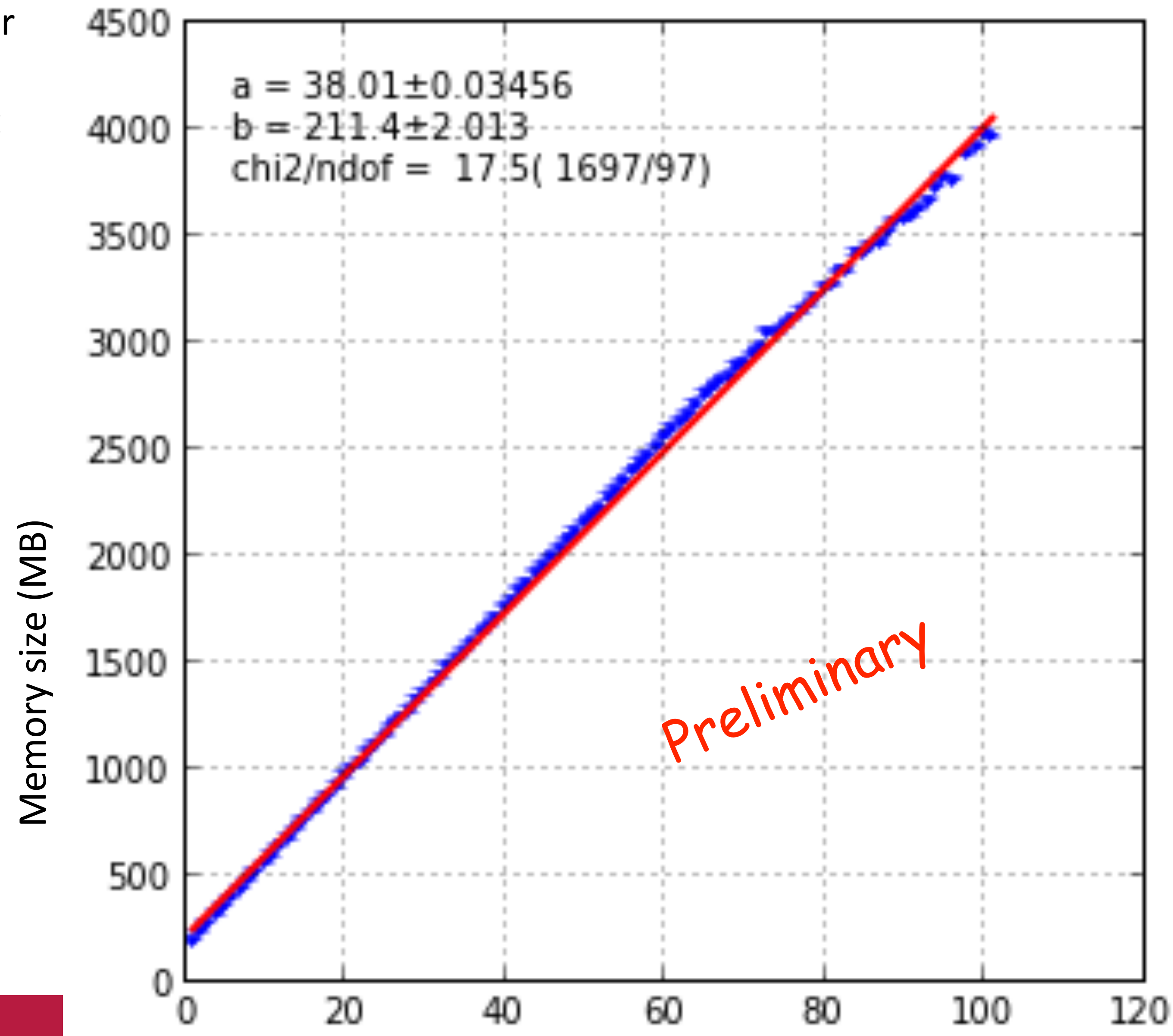
CPU + coprocessor combined results



- First look at total throughput: Events/s
  - 8 core Xeon CPU + 1 Xeon Phi (60 core)
- Very promising results
  - Up to 8 Xeon Phi cards can be hosted by single machine
- Further optimization foreseen

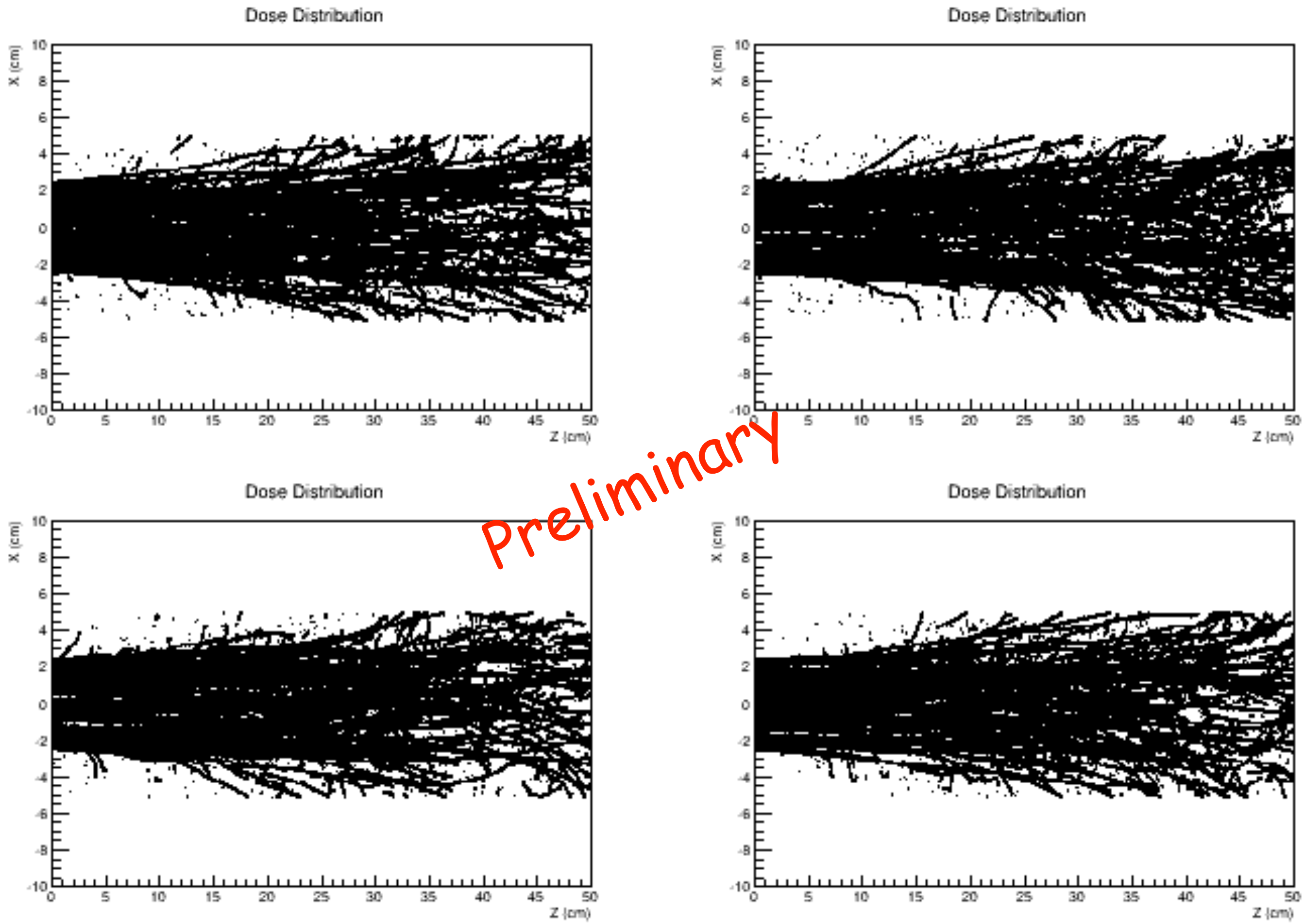
Memory consumption

- Geant4 compiled for MIC architecture
- No optimization yet
- 40MB /thread additional memory usage



MPI + multi-threading

- Geant4 version 10 works with MPI.
  - Many nodes of many cores



- 4 MPI processes with 2 cores each
- Each MPI process owns histogram
- Threads merge dose calculation in shared histogram

Preliminary studies on TBB

- Intel Threading Building Block is a library for task-based multi-threading code. Some LHC experiments show their interest in the use of TBB in their frameworks.
- We have verified that the G4MT can be used in a TBB-based application where TBB-tasks are responsible for simulating events.
  - We didn't need to modify any concrete G4MT class to adapt to TBB.
- A simple test code has been prepared that uses TBB and G4MT.
- We keep investigating where/how to reduce memory use.
- We will provide an example or two at the release of version 10 to demonstrate the way of integrating TBB and G4MT.
  - We will keep communicating with our users to polish our top-level interfaces.

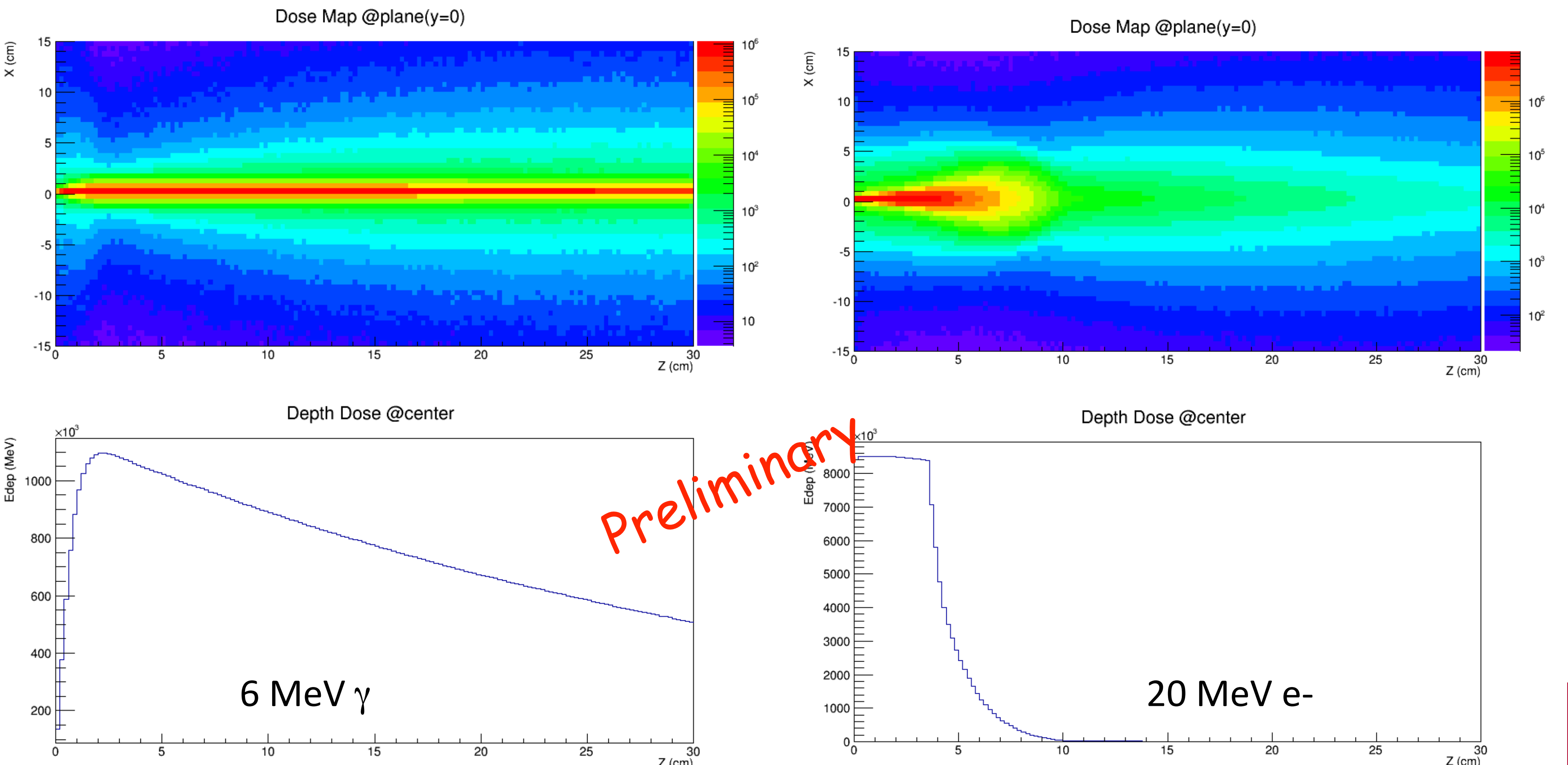
Geant4 - future

- Geant4 version 10 series
  - First public release : Dec. 2013
  - Improvements / optimizations / internal design revisions follow
  - Major API will be kept at least for a few years.
- Cache-hit-rate?
  - ASCR colleagues measured the cache-hit-rate of the latest prototype with full-CMS geometry.

    "Data cache-hit-rate is really good, operation cache-hit-rate is even better."
  - We still have places to improve.
- Use of TLS
  - Two hot spots are to be addressed.
    - Random number engine
    - Ion/isomer table
- GPGPU
  - We think GPGPU is still premature for whole Geant4-based simulation, but hybrid system is within the reachable range.
  - The Geant4 collaboration is engaging to several exploring activities.

EM physics on GPU/Cuda

- SLAC / Stanford-ICME / KEK / NVIDIA project
- Full EM physics up to ~100 MeV for electron / positron / gamma
  - Only one kind of material (water) with different densities
  - No geometrical navigation – regular boxes in a world
- Benchmark on TESLA K20 shows >O(10^2) faster than single core of i-7.



To sum up

- Geant4 is now in its 15th year of production phase.
- Despite its age, it is yet evolving and being enriched with new functionalities.
  - This demonstrates the advantage of the use of OO technologies.
  - And shows the appropriateness of the early design adopted 19 years ago.
- Improvement of physics quality and speed remains a priority to Geant4.
- New technologies trigger in-depth rethinking of simulation paradigm.
  - Many options, many possibilities,
- Geant4 has accommodated part of these by providing a multi-threading solution, based on event-parallelism.
  - That will become the Geant4 version 10.0 to be released in Dec. 2013.
  - Available on both x86_64 and MIC architectures.
  - MPI + MT
- We keep eyes on all other opportunities.
  - Hybrid simulation with EM physics being delegated to GPGPU looks promising.